1.3 Groundwater Storage Change (ΔG_i)

Basic formulation for the estimation is following equation.

$$q_{i,t} = \Delta l_{i,t} \times A_i \times K_i \quad \text{.....(G-1.1)}$$

where;

- $q_{i,t}$: groundwater storage change at well - i at time - t
- i: well number
- t: time (month)
- $l_{i,t}$: difference between 2 sequential months
  e.g. $\Delta l_{it} = l_{i,t} - l_{i,t-1}$

where;

- $l_{i,t}$: observed water level at well - i at time - t
- $l_{i,t-1}$: observed water level at well - i at time, t-1
- A_i : control area (or Thiessen Polygon) of a well - i
- K_i : representative storativity of the control area

Through this project, the number of observation well has increased and reached 51 sites over the project area. Among the wells, 24 wells have produced satisfactory hydrographs from Dec. 1975 to today. Other 27 wells' hydrograph have been available from 1984. Fig. G-1-2 shows the difference of the observation terms of the wells and that the 24 long-term observation wells were not enough for the analysis of the total study area. Consequently, the short-term observation wells were used supplementally for the overall water level estimation.

While the water levels were estimated, storativity each well was assumed.

Those estimation work are summarized in Fig. G-1-3 diagramatically.

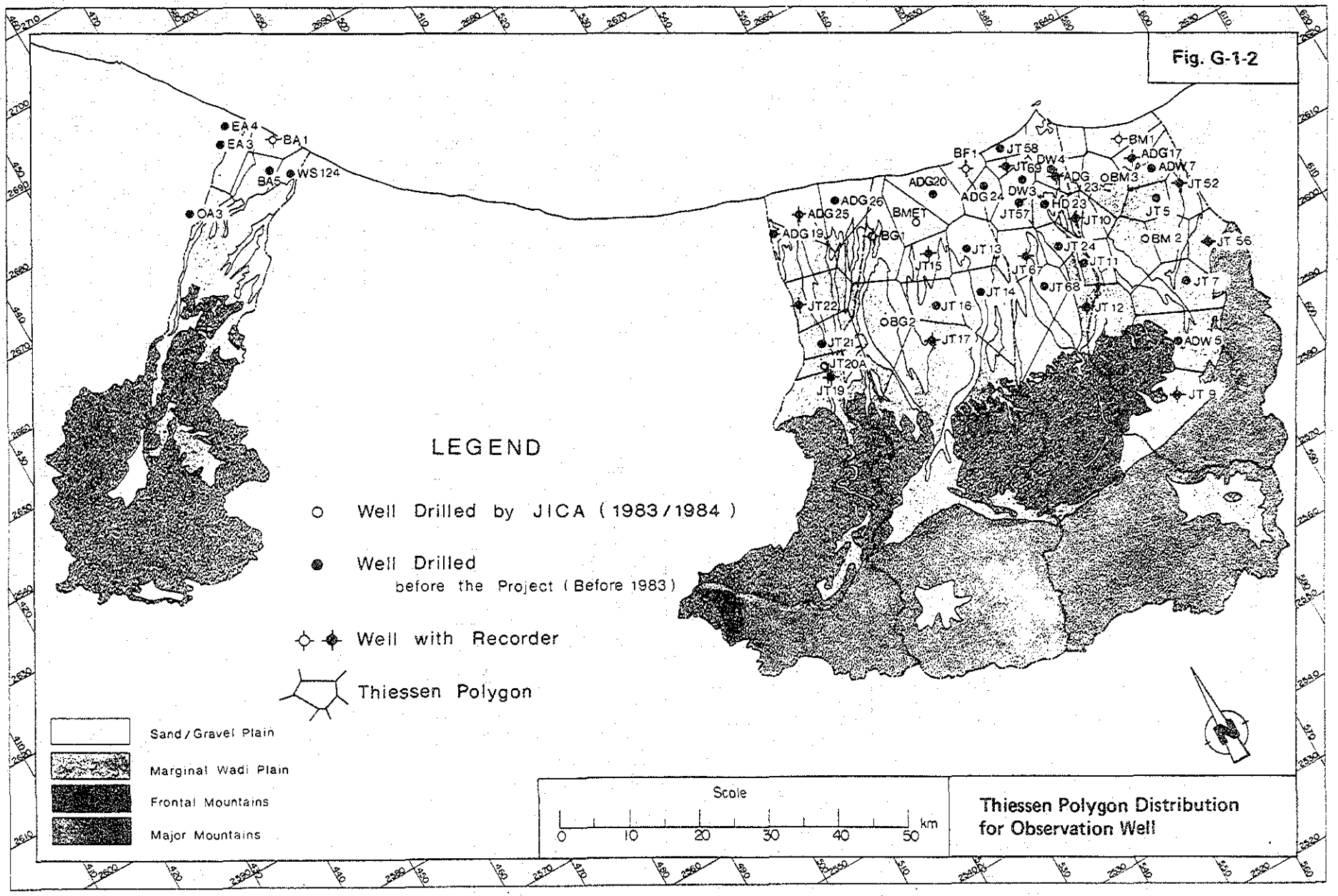
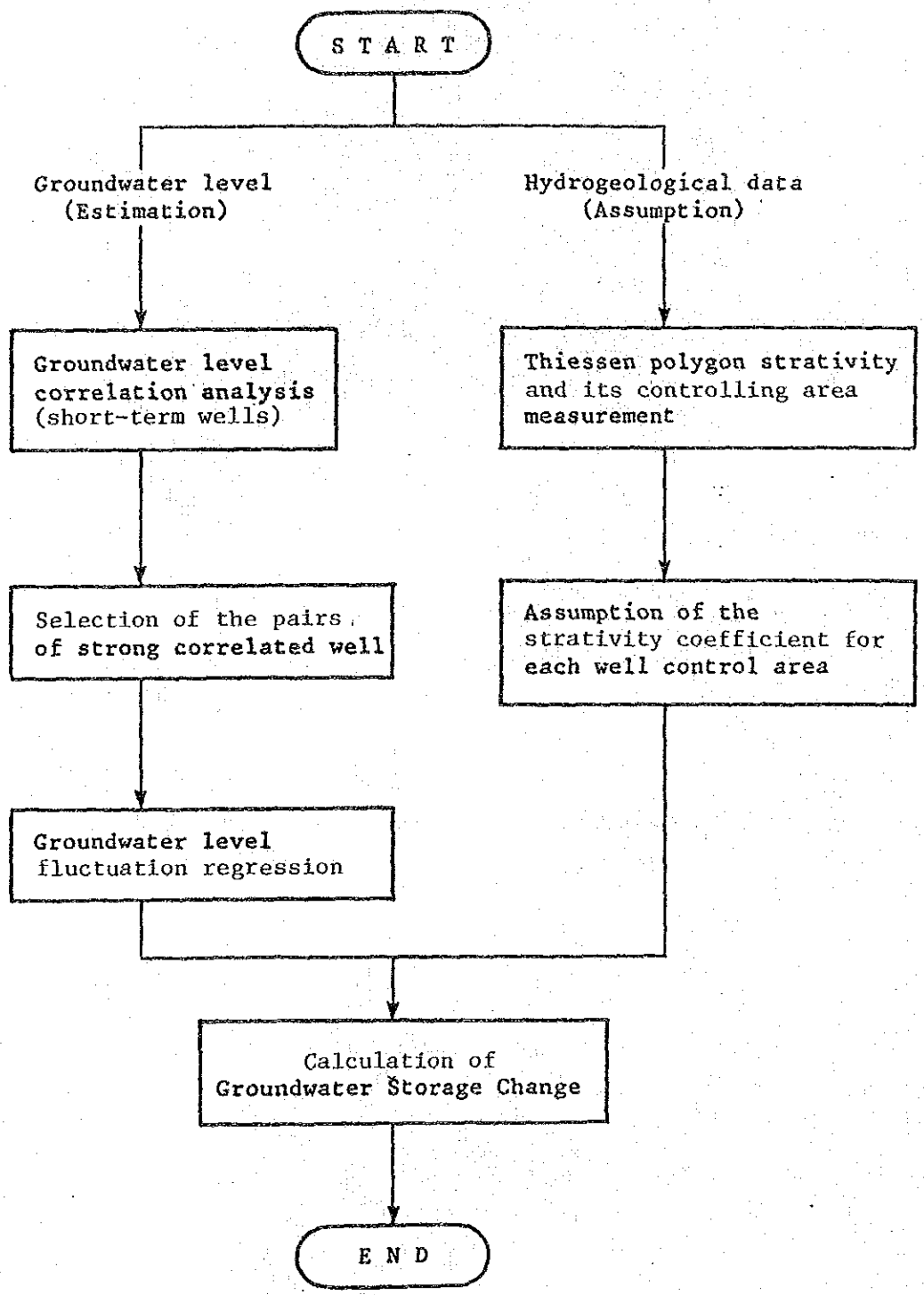


Fig. G-1-2
EA4
EA3
BA1
BA5
WS124
OA3
BF1
JT58
DW4
JT69
ADG17
ADW7
BM1
ADG20
ADG24
DW3
ADG23
OBM3
JT52
ADG26
ADG25
BMET
JT57
HD23
JT10
JT5
ADG19
BG1
JT13
JT24
OBM2
JT56
JT15
JT11
JT67
JT68
JT7
JT14
JT22
JT16
JT12
OBG2
JT17
ADW5
JT21
JT20A
JT19
JT9
LEGEND
Well Drilled by JICA (1983/1984)
Well Drilled
before the Project (Before 1983)
Well with Recorder
Thiessen Polygon
Sand/Gravel Plain
Marginal Wadi Plain
Frontal Mountains
Major Mountains
Scale
0
10
20
30
40
50
km
Thiessen Polygon Distribution
for Observation Well

Fig.G-1-3 Computation Procedure of Groundwater Storage Change Estimation



i. Groundwater level estimation

For regression of the water level at 21 short-term observation wells, correlation analysis were executed with groundwater level data from Dec. 1983 to Dec. 1984. Among the results of correlation analysis, we selected pairs of strongly correlated wells considerating the well location. Groundwater levels were estimated by regression equation derived from correlation analysis.

a. Groundwater level correlation analysis

Groundwater level correlation analysis was executed with the data of 51 wells, whose observation terms were from Dec. 1983 to Dec. 1984, as a single correlation analysis. Table G-1-8 shows the result as a correlation coefficient matrix.

b. Selection of the pair of strongly correlated wells

Strongly correlated wells (>0.9) were selected for each well from the correlation matrix, considering the well locations. For example, a well in Wadi Ahin was not selected for a well in wadi Al-Ma'awil although the correlation coefficient was high.

c. Groundwater level fluctuation regression

According to the equation of regression derived from the correlation analysis, groundwater level fluctuations were estimated for the term from Dec. 1975 to Nov. 1983.

But for the wells in Wadi Ahin basin correlation analyses were not carried out because any long-term well hydrographs were not available.

ii. Hydrogeological data assumption

Thiessen polygon of each well site was measured of the area. And representative value of storage coefficient storativity was assumed for each well site.

a. Thiessen polygon demarkation and its controlling area measurement

Thiessen polygon was drawn and measured of the area for each well site which was scattered over the gravel plain from Frontal Mountains to the coast (Table G-1-9 and Fig. G-1-2)

b. Assumption of the storage coefficient.

Storage coefficient was assumed with the results of previous studies, hydraulic tests by this project and also the geological informations.

iii. Groundwater storage change calculation

Groundwater storage change at each wadi basin was calculated by the equation G-1-1.

Table G-1-10 shows the result of the annual storage change in each wadi basin.

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 1)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 1 EA4	BASIN 1 EA5	BASIN 1 WS124	BASIN 1 EA3	BASIN 1 OA3	BASIN 2 ADG26	BASIN 2 ADG25	BASIN 2 ADW19	BASIN 2 JT22	BASIN 2 JT21	BASIN 2 JT20A	BASIN 2 JT19	BASIN 3 BF1
BASIN 1 BA1	88.2 (13)	93.0 (13)	94.2 (13)	1.6 (13)	85.6 (13)	93.8 (13)	89.7 (13)	89.6 (13)	85.1 (13)	64.2 (13)	90.9 (13)	82.6 (13)	94.7 (13)
BASIN 1 EA4		79.2 (13)	77.4 (13)	24.3 (13)	69.1 (13)	77.7 (13)	71.4 (13)	75.9 (13)	68.8 (13)	37.0 (13)	78.2 (13)	65.7 (13)	83.5 (13)
BASIN 1 EA5			98.5 (13)	28.5 (13)	98.3 (13)	98.8 (13)	96.4 (13)	99.5 (13)	96.4 (13)	84.4 (13)	99.7 (13)	97.3 (13)	87.4 (13)
BASIN 1 WS124				19.4 (13)	95.1 (13)	99.8 (13)	95.6 (13)	97.1 (13)	93.7 (13)	82.1 (13)	97.1 (13)	94.0 (13)	92.8 (13)
BASIN 1 EA3					44.9 (13)	21.7 (13)	35.0 (13)	34.8 (13)	42.7 (13)	67.7 (13)	32.9 (13)	48.4 (13)	13.9 (13)
BASIN 1 OA3						95.7 (13)	95.9 (13)	99.3 (13)	98.0 (13)	91.8 (13)	98.9 (13)	99.8 (13)	77.7 (13)
BASIN 2 ADG26							96.3 (13)	97.5 (13)	94.1 (13)	82.5 (13)	97.7 (13)	94.6 (13)	91.9 (13)
BASIN 2 ADG25								96.1 (13)	95.9 (13)	87.4 (13)	95.7 (13)	94.7 (13)	83.1 (13)
BASIN 2 ADW19									97.4 (13)	87.9 (13)	99.6 (13)	98.7 (13)	83.0 (13)
BASIN 2 JT22										90.3 (13)	96.7 (13)	97.8 (13)	77.3 (13)
BASIN 2 JT21											85.3 (13)	93.2 (13)	57.1 (13)
BASIN 2 JT20A												98.1 (13)	84.2 (13)
BASIN 2 JT19													75.4 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 2)
(MONTHLY DATA WATER LEVEL)

BASIN / STATION	BASIN 3 ADG20	BASIN 3 BMET	BASIN 3 BG1	BASIN 3 JT13	BASIN 3 JT15	BASIN 3 JT14	BASIN 3 JT16	BASIN 3 BG2	BASIN 3 JT17	BASIN 4 JT58	BASIN 4 H8	BASIN 4 JT69	BASIN 4 DW4
BASIN 1 BA1	95.0 (13)	58.1 (13)	83.7 (13)	95.1 (13)	30.4 (13)	61.1 (13)	91.2 (13)	82.5 (13)	72.5 (13)	63.9 (13)	90.6 (13)	92.4 (13)	74.8 (13)
BASIN 1 EA4	81.8 (13)	76.3 (13)	61.5 (13)	88.1 (13)	57.6 (13)	83.0 (13)	76.5 (13)	95.0 (13)	50.1 (13)	35.6 (13)	76.7 (13)	74.7 (13)	64.2 (13)
BASIN 1 EA5	92.3 (13)	37.8 (13)	96.2 (13)	97.1 (13)	29.9 (13)	43.2 (13)	99.8 (13)	75.0 (13)	91.1 (13)	63.4 (13)	82.1 (13)	84.6 (13)	56.4 (13)
BASIN 1 WS124	94.6 (13)	37.9 (13)	94.5 (13)	96.0 (13)	23.1 (13)	43.3 (13)	98.2 (13)	70.1 (13)	87.6 (13)	57.7 (13)	88.1 (13)	91.0 (13)	66.0 (13)
BASIN 1 EA3	2.1 (13)	50.4 (13)	47.9 (13)	10.9 (13)	24.1 (13)	57.8 (13)	31.9 (13)	15.8 (13)	51.9 (13)	17.9 (13)	10.2 (13)	7.8 (13)	46.4 (13)
BASIN 1 OA3	85.6 (13)	23.5 (13)	98.7 (13)	91.9 (13)	24.3 (13)	28.7 (13)	98.9 (13)	66.6 (13)	96.8 (13)	62.9 (13)	73.6 (13)	76.6 (13)	44.5 (13)
BASIN 2 ADG26	94.9 (13)	38.9 (13)	94.8 (13)	96.3 (13)	22.7 (13)	43.1 (13)	98.6 (13)	71.1 (13)	88.2 (13)	64.7 (13)	87.1 (13)	89.9 (13)	62.3 (13)
BASIN 2 ADG25	87.9 (13)	30.8 (13)	96.6 (13)	89.9 (13)	11.3 (13)	28.6 (13)	96.0 (13)	64.5 (13)	91.8 (13)	64.4 (13)	85.3 (13)	86.7 (13)	51.9 (13)
BASIN 2 ADW19	89.2 (13)	30.9 (13)	97.5 (13)	94.7 (13)	28.0 (13)	36.9 (13)	99.6 (13)	71.9 (13)	93.8 (13)	62.4 (13)	78.7 (13)	81.4 (13)	52.7 (13)
BASIN 2 JT22	80.8 (13)	23.8 (13)	97.4 (13)	89.2 (13)	19.7 (13)	28.4 (13)	96.9 (13)	64.8 (13)	95.2 (13)	65.6 (13)	76.9 (13)	78.6 (13)	46.0 (13)
BASIN 2 JT21	87.6 (13)	14.5 (13)	95.5 (13)	70.1 (13)	4.7 (13)	10.7 (13)	86.5 (13)	32.8 (13)	98.6 (13)	65.7 (13)	58.2 (13)	63.0 (13)	29.2 (13)
BASIN 2 JT20A	90.4 (13)	36.5 (13)	96.2 (13)	96.6 (13)	32.1 (13)	41.9 (13)	99.8 (13)	75.4 (13)	92.1 (13)	60.7 (13)	78.2 (13)	80.7 (13)	51.2 (13)
BASIN 2 JT19	83.4 (13)	19.2 (13)	98.6 (13)	90.2 (13)	23.5 (13)	25.2 (13)	98.2 (13)	63.0 (13)	97.7 (13)	63.2 (13)	70.9 (13)	74.0 (13)	41.6 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 3)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 4 ADG23	BASIN 4 JT57	BASIN 4 HD23	BASIN 4 ADG24	BASIN 4 DW3	BASIN 4 JT10	BASIN 4 JT24	BASIN 4 JT67	BASIN 4 JT68	BASIN 4 JT11	BASIN 4 JT12	BASIN 5 BH1	BASIN 5 BH3
BASIN 1 BA1	84.8 (13)	28.7 (13)	72.2 (13)	94.0 (13)	90.9 (13)	93.4 (13)	82.6 (13)	93.3 (13)	91.8 (13)	94.4 (13)	69.7 (13)	93.0 (13)	89.3 (13)
BASIN 1 EA4	73.5 (13)	19.8 (13)	83.9 (13)	75.5 (13)	85.1 (13)	78.0 (13)	67.8 (13)	83.3 (13)	77.7 (13)	86.0 (13)	42.7 (13)	70.5 (13)	74.4 (13)
BASIN 1 EA5	97.5 (13)	48.9 (13)	61.7 (13)	90.2 (13)	94.3 (13)	99.2 (13)	95.7 (13)	99.1 (13)	99.8 (13)	98.2 (13)	88.3 (13)	90.5 (13)	99.5 (13)
BASIN 1 WSI24	95.3 (13)	43.8 (13)	55.5 (13)	95.2 (13)	93.3 (13)	99.4 (13)	92.5 (13)	97.6 (13)	98.3 (13)	96.7 (13)	86.4 (13)	95.7 (13)	97.2 (13)
BASIN 1 EA3	34.4 (13)	44.6 (13)	16.7 (13)	2.6 (13)	8.0 (13)	23.6 (13)	44.1 (13)	21.6 (13)	30.5 (13)	15.8 (13)	63.8 (13)	8.2 (13)	37.2 (13)
BASIN 1 OA3	97.5 (13)	54.6 (13)	55.4 (13)	83.6 (13)	89.8 (13)	96.4 (13)	96.7 (13)	96.2 (13)	98.3 (13)	94.0 (13)	94.3 (13)	85.2 (13)	99.5 (13)
BASIN 2 ADG26	95.5 (13)	46.3 (13)	54.9 (13)	94.8 (13)	93.0 (13)	99.6 (13)	94.0 (13)	98.1 (13)	98.8 (13)	97.2 (13)	86.7 (13)	94.7 (13)	97.7 (13)
BASIN 2 ADG25	91.2 (13)	38.2 (13)	52.8 (13)	91.1 (13)	84.2 (13)	95.3 (13)	92.3 (13)	93.7 (13)	96.2 (13)	91.5 (13)	89.8 (13)	91.7 (13)	96.3 (13)
BASIN 2 ADW19	98.2 (13)	49.9 (13)	59.7 (13)	87.3 (13)	92.6 (13)	98.2 (13)	95.4 (13)	98.0 (13)	99.2 (13)	96.4 (13)	91.0 (13)	88.1 (13)	99.8 (13)
BASIN 2 JT22	96.1 (13)	44.5 (13)	54.3 (13)	83.9 (13)	87.3 (13)	94.3 (13)	93.4 (13)	94.1 (13)	96.5 (13)	91.2 (13)	92.6 (13)	86.1 (13)	97.5 (13)
BASIN 2 JT21	86.2 (13)	53.7 (13)	27.9 (13)	69.8 (13)	68.9 (13)	82.9 (13)	86.0 (13)	78.7 (13)	84.8 (13)	74.1 (13)	99.4 (13)	75.3 (13)	88.4 (13)
BASIN 2 JT20A	97.9 (13)	52.1 (13)	62.0 (13)	87.2 (13)	94.1 (13)	98.4 (13)	96.6 (13)	99.0 (13)	99.7 (13)	97.9 (13)	89.0 (13)	87.3 (13)	99.7 (13)
BASIN 2 JT19	97.7 (13)	56.7 (13)	51.8 (13)	81.4 (13)	88.7 (13)	95.4 (13)	96.8 (13)	94.9 (13)	97.5 (13)	92.6 (13)	95.4 (13)	83.4 (13)	98.9 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 4)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN S ADW7	BASIN S ADG17	BASIN S JTS	BASIN S JTS2	BASIN S JTS6	BASIN S JT7	BASIN S ADW5	BASIN S JT9
BASIN 1 BA1	87.1 (13)	97.3 (13)	5.2 (13)	78.1 (13)	85.0 (13)	96.6 (13)	89.7 (13)	96.3 (13)
BASIN 1 EA4	66.7 (13)	82.7 (13)	26.0 (13)	53.6 (13)	67.3 (13)	83.9 (13)	75.0 (13)	87.2 (13)
BASIN 1 EA5	97.4 (13)	98.0 (13)	17.5 (13)	93.4 (13)	98.0 (13)	93.6 (13)	99.6 (13)	98.5 (13)
BASIN 1 WSI24	96.9 (13)	98.8 (13)	19.1 (13)	92.4 (13)	95.8 (13)	96.1 (13)	97.4 (13)	97.7 (13)
BASIN 1 EA3	40.1 (13)	14.9 (13)	57.4 (13)	52.0 (13)	43.4 (13)	4.6 (13)	35.5 (13)	13.8 (13)
BASIN 1 OA3	98.1 (13)	93.5 (13)	27.3 (13)	97.0 (13)	99.5 (13)	86.8 (13)	99.4 (13)	93.9 (13)
BASIN 2 ADG26	96.9 (13)	98.7 (13)	18.0 (13)	92.5 (13)	96.1 (13)	96.0 (13)	97.8 (13)	98.0 (13)
BASIN 2 ADG25	97.2 (13)	96.2 (13)	33.8 (13)	93.5 (13)	95.4 (13)	92.5 (13)	96.0 (13)	93.3 (13)
BASIN 2 ADW19	98.0 (13)	96.0 (13)	22.3 (13)	95.2 (13)	99.0 (13)	90.7 (13)	99.8 (13)	96.7 (13)
BASIN 2 JT22	97.9 (13)	93.1 (13)	29.2 (13)	95.1 (13)	97.7 (13)	86.6 (13)	97.3 (13)	92.2 (13)
BASIN 2 JT21	92.2 (13)	77.1 (13)	55.2 (13)	97.5 (13)	92.3 (13)	68.7 (13)	87.8 (13)	74.2 (13)
BASIN 2 JT20A	96.9 (13)	96.6 (13)	16.6 (13)	93.4 (13)	98.3 (13)	91.3 (13)	99.8 (13)	97.8 (13)
BASIN 2 JT19	97.7 (13)	91.7 (13)	28.2 (13)	97.5 (13)	99.6 (13)	84.7 (13)	98.8 (13)	92.2 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 5)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 3 ADG2O	BASIN 3 BMET	BASIN 3 BG1	BASIN 3 JT13	BASIN 3 JT15	BASIN 3 JT14	BASIN 3 JT16	BASIN 3 BG2	BASIN 3 JT17	BASIN 4 JT58	BASIN 4 H8	BASIN 4 JT69	BASIN 4 DW4
BASIN 3 BF1	94.1 (13)	58.2 (13)	76.4 (13)	91.7 (13)	25.1 (13)	62.2 (13)	85.7 (13)	72.3 (13)	64.2 (13)	62.0 (13)	93.6 (13)	95.0 (13)	80.0 (13)
BASIN 3 ADG2O		49.3 (13)	84.2 (13)	94.3 (13)	25.1 (13)	53.7 (13)	91.2 (13)	75.6 (13)	74.1 (13)	58.3 (13)	84.7 (13)	89.3 (13)	70.7 (13)
BASIN 3 BMET			13.6 (13)	55.2 (13)	49.1 (13)	90.6 (13)	34.1 (13)	78.0 (13)	.4 (13)	4.5 (13)	51.4 (13)	46.0 (13)	39.4 (13)
BASIN 3 BG1				87.0 (13)	10.5 (13)	17.4 (13)	96.9 (13)	57.1 (13)	98.1 (13)	68.1 (13)	75.6 (13)	79.4 (13)	47.7 (13)
BASIN 3 JT13					44.8 (13)	62.1 (13)	96.2 (13)	84.9 (13)	79.5 (13)	56.6 (13)	81.6 (13)	83.3 (13)	59.8 (13)
BASIN 3 JT15						73.2 (13)	29.2 (13)	63.4 (13)	9.4 (13)	6.3 (13)	4.9 (13)	2.1 (13)	12.4 (13)
BASIN 3 JT14							40.2 (13)	83.3 (13)	4.6 (13)	10.4 (13)	47.3 (13)	44.3 (13)	51.5 (13)
BASIN 3 JT16								72.6 (13)	92.6 (13)	64.2 (13)	79.9 (13)	82.8 (13)	54.4 (13)
BASIN 3 BG2									47.1 (13)	20.6 (13)	62.7 (13)	61.8 (13)	48.7 (13)
BASIN 3 JT17										64.9 (13)	63.2 (13)	67.0 (13)	32.7 (13)
BASIN 4 JT58											59.5 (13)	63.7 (13)	63.5 (13)
BASIN 4 H8												98.7 (13)	79.0 (13)
BASIN 4 JT69													82.5 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 6)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 4 ADG23	BASIN 4 JT57	BASIN 4 HD23	BASIN 4 ADG24	BASIN 4 DW3	BASIN 4 JT10	BASIN 4 JT24	BASIN 4 JT67	BASIN 4 JT68	BASIN 4 JT11	BASIN 4 JT12	BASIN 5 BM1	BASIN 5 BM3
BASIN 3 BF1	81.2 (13)	24.6 (13)	56.1 (13)	95.7 (13)	87.2 (13)	90.5 (13)	77.7 (13)	88.7 (13)	87.0 (13)	89.9 (13)	63.6 (13)	94.3 (13)	83.2 (13)
BASIN 3 ADG20	85.3 (13)	45.5 (13)	61.0 (13)	93.5 (13)	90.1 (13)	94.5 (13)	85.7 (13)	93.0 (13)	91.5 (13)	94.3 (13)	72.5 (13)	91.5 (13)	89.2 (13)
BASIN 3 BMET	27.7 (13)	10.1 (13)	53.4 (13)	46.8 (13)	48.6 (13)	38.5 (13)	31.5 (13)	45.5 (13)	37.8 (13)	50.9 (13)	5.9 (13)	35.3 (13)	31.0 (13)
BASIN 3 BG1	94.7 (13)	49.9 (13)	47.9 (13)	85.2 (13)	84.6 (13)	95.1 (13)	93.4 (13)	92.6 (13)	96.0 (13)	89.7 (13)	97.2 (13)	88.2 (13)	97.7 (13)
BASIN 3 JT13	93.8 (13)	48.3 (13)	69.2 (13)	88.8 (13)	97.0 (13)	96.7 (13)	92.4 (13)	98.8 (13)	97.0 (13)	99.6 (13)	75.7 (13)	87.0 (13)	95.0 (13)
BASIN 3 JT15	35.6 (13)	38.6 (13)	66.9 (13)	5.2 (13)	52.4 (13)	24.7 (13)	28.9 (13)	36.7 (13)	29.9 (13)	42.1 (13)	.9 (13)	3.0 (13)	27.1 (13)
BASIN 3 JT14	39.0 (13)	9.2 (13)	68.7 (13)	44.2 (13)	62.9 (13)	43.3 (13)	34.6 (13)	51.6 (13)	42.7 (13)	58.0 (13)	2.8 (13)	36.4 (13)	36.1 (13)
BASIN 3 JT16	98.1 (13)	51.8 (13)	59.3 (13)	89.0 (13)	94.3 (13)	99.0 (13)	96.4 (13)	98.8 (13)	99.8 (13)	97.7 (13)	90.1 (13)	89.6 (13)	99.7 (13)
BASIN 3 BG2	69.4 (13)	29.6 (13)	85.0 (13)	65.5 (13)	81.5 (13)	73.2 (13)	65.9 (13)	80.6 (13)	73.7 (13)	83.1 (13)	39.3 (13)	59.0 (13)	70.9 (13)
BASIN 3 JT17	92.5 (13)	56.4 (13)	40.1 (13)	74.3 (13)	78.2 (13)	88.8 (13)	92.0 (13)	86.7 (13)	91.4 (13)	83.0 (13)	99.0 (13)	78.4 (13)	94.2 (13)
BASIN 4 JT58	62.0 (13)	24.0 (13)	40.3 (13)	61.4 (13)	62.1 (13)	61.8 (13)	58.5 (13)	56.8 (13)	62.8 (13)	57.7 (13)	65.4 (13)	72.2 (13)	62.6 (13)
BASIN 4 H8	73.8 (13)	1.0 (13)	47.4 (13)	96.1 (13)	74.4 (13)	85.1 (13)	68.3 (13)	81.1 (13)	81.2 (13)	80.2 (13)	63.4 (13)	95.2 (13)	78.3 (13)
BASIN 4 JT69	76.2 (13)	9.9 (13)	47.3 (13)	98.4 (13)	77.5 (13)	88.2 (13)	71.2 (13)	83.4 (13)	83.5 (13)	82.6 (13)	67.9 (13)	98.0 (13)	80.8 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 7)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 5 ADW7	BASIN 5 ADG17	BASIN 5 JT5	BASIN 5 JT52	BASIN 5 JT56	BASIN 5 JT7	BASIN 5 ADW5	BASIN 5 JT9
BASIN 3 BF1	82.6 (13)	93.6 (13)	1.0 (13)	73.0 (13)	79.1 (13)	96.4 (13)	83.4 (13)	92.1 (13)
BASIN 3 ADG20	86.4 (13)	94.4 (13)	4.1 (13)	80.9 (13)	85.5 (13)	93.9 (13)	89.6 (13)	94.4 (13)
BASIN 3 BMET	21.2 (13)	47.6 (13)	55.6 (13)	4.0 (13)	21.7 (13)	55.1 (13)	31.8 (13)	52.1 (13)
BASIN 3 BG1	99.0 (13)	92.2 (13)	39.5 (13)	99.1 (13)	98.6 (13)	85.8 (13)	97.4 (13)	90.3 (13)
BASIN 3 JT13	89.9 (13)	96.8 (13)	2.9 (13)	83.0 (13)	91.3 (13)	94.0 (13)	95.4 (13)	98.3 (13)
BASIN 3 JT15	11.9 (13)	25.7 (13)	65.5 (13)	6.0 (13)	23.0 (13)	20.6 (13)	29.4 (13)	37.0 (13)
BASIN 3 JT14	24.5 (13)	49.9 (13)	69.3 (13)	9.3 (13)	27.9 (13)	53.8 (13)	37.9 (13)	57.0 (13)
BASIN 3 JT16	97.7 (13)	97.2 (13)	18.6 (13)	94.6 (13)	98.8 (13)	92.0 (13)	99.9 (13)	97.7 (13)
BASIN 3 BG2	60.8 (13)	75.8 (13)	32.3 (13)	46.8 (13)	62.8 (13)	74.1 (13)	71.6 (13)	83.0 (13)
BASIN 3 JT17	95.6 (13)	84.0 (13)	43.9 (13)	98.6 (13)	96.8 (13)	75.7 (13)	93.8 (13)	82.7 (13)
BASIN 4 JT58	67.1 (13)	66.5 (13)	27.7 (13)	67.6 (13)	67.2 (13)	62.2 (13)	63.5 (13)	58.3 (13)
BASIN 4 H8	82.0 (13)	90.5 (13)	23.1 (13)	71.5 (13)	74.8 (13)	95.0 (13)	77.9 (13)	85.6 (13)
BASIN 4 JT69	84.7 (13)	92.1 (13)	24.3 (13)	76.1 (13)	78.0 (13)	95.2 (13)	80.7 (13)	87.1 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 8)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 4 ADG23	BASIN 4 JT57	BASIN 4 HD23	BASIN 4 ADG24	BASIN 4 DW3	BASIN 4 JT10	BASIN 4 JT24	BASIN 4 JT67	BASIN 4 JT68	BASIN 4 JT11	BASIN 4 JT12	BASIN 5 BM1	BASIN 5 BM3
BASIN 4 DW4	49.1 (13)	8.0 (13)	50.8 (13)	75.3 (13)	62.9 (13)	61.2 (13)	35.7 (13)	56.0 (13)	53.5 (13)	58.3 (13)	33.4 (13)	77.2 (13)	50.1 (13)
BASIN 4 ADG23		56.7 (13)	56.1 (13)	82.4 (13)	93.8 (13)	96.4 (13)	95.1 (13)	96.7 (13)	97.8 (13)	95.3 (13)	89.5 (13)	84.0 (13)	98.1 (13)
BASIN 4 JT57			22.0 (13)	22.1 (13)	52.9 (13)	47.8 (13)	62.7 (13)	50.5 (13)	50.7 (13)	51.6 (13)	53.8 (13)	23.6 (13)	51.7 (13)
BASIN 4 HD23				46.7 (13)	70.1 (13)	56.4 (13)	49.6 (13)	64.2 (13)	58.8 (13)	67.3 (13)	30.7 (13)	47.0 (13)	58.0 (13)
BASIN 4 ADG24					83.0 (13)	93.5 (13)	80.7 (13)	89.6 (13)	89.7 (13)	88.7 (13)	74.9 (13)	98.4 (13)	87.3 (13)
BASIN 4 DW3						93.5 (13)	89.7 (13)	96.0 (13)	94.2 (13)	97.6 (13)	73.6 (13)	82.3 (13)	92.2 (13)
BASIN 4 JT10							93.9 (13)	98.7 (13)	99.0 (13)	97.6 (13)	87.4 (13)	93.3 (13)	98.3 (13)
BASIN 4 JT24								94.9 (13)	96.9 (13)	94.2 (13)	89.2 (13)	80.4 (13)	96.7 (13)
BASIN 4 JT67									99.1 (13)	99.3 (13)	83.4 (13)	88.4 (13)	98.1 (13)
BASIN 4 JT68										98.1 (13)	88.8 (13)	89.8 (13)	99.5 (13)
BASIN 4 JT11											79.1 (13)	87.0 (13)	96.5 (13)
BASIN 4 JT12												79.6 (13)	91.8 (13)
BASIN 5 BM1													88.2 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 9)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 5 ADW7	BASIN 5 ADG17	BASIN 5 JT5	BASIN 5 JT52	BASIN 5 JT56	BASIN 5 JT7	BASIN 5 ADW5	BASIN 5 JT9
BASIN 4 DW4	53.1 (13)	66.7 (13)	2.6 (13)	44.7 (13)	47.8 (13)	70.8 (13)	51.3 (13)	62.4 (13)
BASIN 4 ADG23	95.8 (13)	92.7 (13)	14.5 (13)	93.6 (13)	97.9 (13)	87.0 (13)	98.3 (13)	94.7 (13)
BASIN 4 JT57	43.9 (13)	36.2 (13)	15.7 (13)	53.3 (13)	53.3 (13)	24.8 (13)	53.0 (13)	42.7 (13)
BASIN 4 HD23	48.8 (13)	62.0 (13)	23.9 (13)	39.3 (13)	51.5 (13)	57.1 (13)	59.0 (13)	67.0 (13)
BASIN 4 ADG24	89.6 (13)	95.6 (13)	22.5 (13)	82.3 (13)	84.7 (13)	97.1 (13)	87.2 (13)	92.0 (13)
BASIN 4 DW3	86.3 (13)	93.0 (13)	10.8 (13)	81.1 (13)	90.5 (13)	88.1 (13)	93.5 (13)	96.0 (13)
BASIN 4 JT10	97.1 (13)	98.1 (13)	18.1 (13)	93.0 (13)	96.5 (13)	94.9 (13)	98.4 (13)	98.3 (13)
BASIN 4 JT24	93.0 (13)	91.2 (13)	12.5 (13)	91.6 (13)	96.6 (13)	85.4 (13)	96.8 (13)	92.3 (13)
BASIN 4 JT67	94.6 (13)	97.3 (13)	8.3 (13)	89.4 (13)	95.5 (13)	93.0 (13)	98.4 (13)	99.3 (13)
BASIN 4 JT68	97.3 (13)	97.7 (13)	16.6 (13)	93.5 (13)	98.2 (13)	93.2 (13)	99.6 (13)	98.2 (13)
BASIN 4 JT11	91.6 (13)	97.1 (13)	.6 (13)	85.9 (13)	93.6 (13)	93.4 (13)	97.0 (13)	99.3 (13)
BASIN 4 JT12	95.0 (13)	81.8 (13)	51.3 (13)	98.9 (13)	94.7 (13)	74.2 (13)	91.1 (13)	79.4 (13)
BASIN 5 BH1	92.0 (13)	95.2 (13)	30.5 (13)	86.1 (13)	86.6 (13)	95.5 (13)	88.0 (13)	90.4 (13)

NOTE ( ):Number of data

Table G-1-8 CORRELATION COEFFICIENT (%) of WATER LEVEL (1984) (Sheet 10)
(MONTHLY DATA WATER LEVEL)

BASIN STATION	BASIN 5 ADW7	BASIN 5 ADG17	BASIN 5 JT5	BASIN 5 JT52	BASIN 5 JT56	BASIN 5 JT7	BASIN 5 ADW5	BASIN 5 JT9
BASIN 5 BM3	98.2 (13)	96.0 (13)	22.6 (13)	95.5 (13)	99.1 (13)	90.7 (13)	99.9 (13)	96.7 (13)
BASIN 5 ADW7		94.9 (13)	37.0 (13)	98.0 (13)	98.2 (13)	90.2 (13)	97.8 (13)	93.2 (13)
BASIN 5 ADG17			15.0 (13)	88.2 (13)	93.7 (13)	98.1 (13)	96.2 (13)	98.6 (13)
BASIN 5 JT5				44.4 (13)	27.0 (13)	12.3 (13)	20.0 (13)	5.8 (13)
BASIN 5 JT52					97.4 (13)	81.4 (13)	95.2 (13)	86.3 (13)
BASIN 5 JT56						87.6 (13)	99.1 (13)	93.4 (13)
BASIN 5 JT7							90.6 (13)	96.0 (13)
BASIN 5 ADW5								96.9 (13)

NOTE ( ):Number of data

Table G-1-9 Thiessen Polygon Distribution for Observation Well

(KM2)

Symbol	W. Ahin	W.B. Ghafir	W. Al-Fara'	W.B.Kharus	W.Al-Ma'awil	Total	Storage Coefficient	
BA1	18.12	0.0	0.0	0.0	0.0	18.12	A	
JT20A	0.0	10.36	5.0	0.0	0.0	15.36	C	
BM1	0.0	0.0	0.0	0.0	35.01	35.01	A	1.0
BF1	0.0	0.0	12.0	7.94	0.0	19.94	B	0.5
BG2	0.0	20.0	113.33	0.0	0.0	133.33	D	0.1
BG1	0.0	26.0	54.88	0.0	0.0	80.88	B	0.5
BM3	0.0	0.0	0.0	0.0	42.59	42.59	B	0.5
BMET	0.0	41.82	0.0	0.0	0.0	41.82	A	0
ADG20	0.0	33.48	0.0	0.0	0.0	33.48	A	0
OA3	32.76	0.0	0.0	0.0	0.0	32.76	C	0
WSI24	30.37	0.0	0.0	0.0	0.0	30.37	B	0.5
EA3	18.7	0.0	0.0	0.0	0.0	18.7	C	0.3
EA4	3.69	0.0	0.0	0.0	0.0	3.69	C	0.3
EA5	34.52	0.0	0.0	0.0	0.0	34.52	B	0.5
JT58	0.0	0.0	6.50	6.77	0.0	13.27	C	0.3
JT5	0.0	0.0	0.0	0.0	31.29	31.29	C	0.3
JT7	0.0	0.0	0.0	0.0	69.81	69.81	C	0

(Continued)

Symbol	W. Ahin	W.B. Ghafir	W. Al-Fara'	W.B.Kharus	W.Al-Ma'awil	Total	Storage Coefficient	
JT10	0.0	0.0	0.0	10.50	21.00	31.50	B	0
JT69	0.0	0.0	0.0	10.44	0.0	10.44	C	0.3
JT11	0.0	0.0	0.0	25.41	16.94	42.35	C	0.3
JT12	0.0	0.0	0.0	61.11	50.11	111.11	D	0.1
JT15	0.0	44.19	0.0	0.0	0.0	44.19	C	0.3
JT16	0.0	45.06	0.0	0.0	0.0	45.06	C	0
JT17	0.0	149.05	0.0	0.0	0.0	149.05	C	0
JT19	0.0	12.10	24.24	0.0	0.0	36.34	C	C
JT21	0.0	26.02	6.5	0.0	0.0	32.52	C	
JT22	0.0	53.60	0.0	0.0	0.0	53.60	C	
JT24	0.0	0.0	0.0	23.41	0.0	23.41	C	
JT52	0.0	0.0	0.0	0.0	25.64	25.64	B	0
JT56	0.0	0.0	0.0	0.0	28.75	28.75	C	0
JT57	0.0	0.0	0.0	30.65	0.0	30.65	B	0.5
JT67	0.0	0.0	4.8	37.06	0.0	41.86	C	0.3
JT68	0.0	0.0	0.0	166.20	0.0	166.20	B	0
ADW19	0.0	45.70	0.0	0.0	0.0	45.70	A	0
HD23	0.0	0.0	0.0	23.57	0.0	23.57	B	0
ADG26	0.0	51.31	8.0	0.0	0.0	59.31	A	0
ADG25	0.0	47.47	0.0	0.0	0.0	47.47	A	0
DW4	0.0	0.0	0.0	18.22	9.0	27.22	B	0
DW3	0.0	0.0	0.0	16.83	0.0	16.83	B	0
ADG23	0.0	0.0	0.0	18.22	9.0	27.22	B	0
ADW5	0.0	0.0	0.0	0.0	69.73	69.73	C	0

(Continued)

Symbol	W. Ahin	W.B. Ghafir	W. Al-Fara'	W.B.Kharus	W.Al-Ma'awil	Total	Storage Coefficient	
ADW7	0.0	0.0	0.0	0.0	27.99	27.99	B	0
ADW24	0.0	0.0	11.68	17.51	0.0	29.19	B	0
JT13	0.0	0.0	48.27	1.75	0.0	50.02	B	0.5
JT14	0.0	0.0	69.96	0.0	0.0	69.96	C	0
ADG17	0.0	0.0	0.0	0.0	23.14	23.14	B	0

Storage Coefficient: A: 0.015, B. 0.005, C: 0,003, D: 0.001

Table G-1-10 Estimated Results of Annual Groundwater Storage Change

W.Ahin (MCM/Year)

	76	77	78	79	80	81	82	83	84	Average
Upper	-	-	-	-	-	-	-	-	-	-
Lower	-	-	-	-	-	-	-	-	1.07	1.07

W.B. Ghafir (MCM/Year)

	76	77	78	79	80	81	82	83	84	Average
Upper	-	-	-	-	-	-	-	-	-	-
Lower	-1.49	-1.06	0.78	0.88	-0.44	1.38	-0.25	-2.93	0.69	-0.23

W.Al-Fara' (MCM/Year)

	76	77	78	79	80	81	82	83	84	Average
Upper	-	-	-	-	-	-	-	-	-	-
Lower	-0.92	-0.98	1.23	0.28	-0.88	0.86	-0.56	-8.55	0.77	-1.05

W.B.Kharus (MCM/Year)

	76	77	78	79	80	81	82	83	84	Average
Upper	-	-	-	-	-	-	-	-	-	-
Lower	0.66	-0.26	-0.56	0.39	0.81	-0.12	-1.25	-1.80	-0.93	-0.41

W.Al-Ma'awil (MCM/Year)

	76	77	78	79	80	81	82	83	84	Average
Upper	-	-	-	-	-	-	-	-	-	-
Lower	-1.18	-1.29	-1.22	1.54	1.68	0.30	-1.20	-2.93	4.02	-0.03

1.4 Surface discharge to lower stream (Di)

Five surface discharge events to lower stream (Di) were observed from Dec. 1983 to Dec. 1984. But there is no available data for the term from Jan. 1977 to Nov. 1983. And also there is no data of the discharge to the sea (D_2). Eventually, as mentioned in Main report 4.2, estimation by Horn (1979) was adopted.

1.5 Subsurface discharge to lower stream (I_i)

Subsurface discharges to the sea (I_2) of wadi were estimated from the hydraulic gradient along the wadi bed surveyed in 1985. Only in Wadi Al-Ahin such discharge was confirmed as estimated in the following:

Groundwater discharge to the sea would be-formulated as

$$D = I \times T \times B \times 365 \text{ days} \times 10^{-6}$$

where

D = Subsurface discharge to the sea (MCM/year)
I = Hydraulic gradient
T = Transmissibility (m^2/day)
B = Width of the coastal aquifer (m)

Hydraulic gradient was determined by the groundwater level survey carried out in 1985 (cf. Main Chapter 4).

Transmissibility was estimated by averaging the values of several wells (cf. Main Report Table 4-3-2).

Width of the coastal aquifer was estimated about 10,000 m by the 1/100,000 map topographed. So that the annual discharge would be calculated as following:

$D = 5.3 \times 10^{-4}$ 2m699 m^2/day x 10,000 m x 365 days x 10^{-6}
$= 5.12$
$\fallingdotseq$ 5.1 (MCM/year)

CHAPTER 2 ESTIMATION OF THE HYDROLOGIC WATER BALANCE

In the preceeding section and Main Report Chapter5, the regional hydrologic cycles were estimated through observed terms.

In this section, the hydrologic water balance would be estimated with some assumptions presented in Fig. G-2-3.

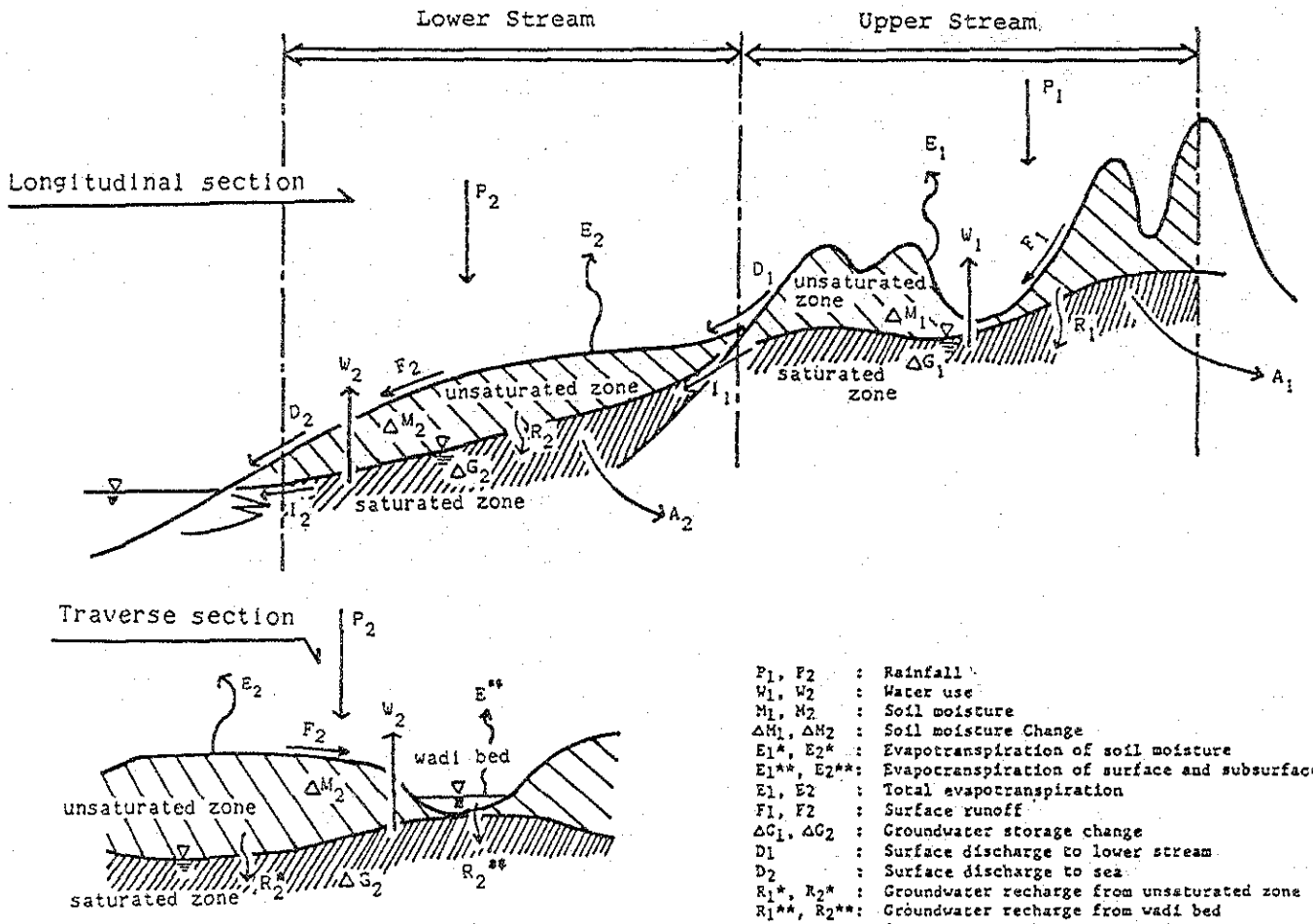
This water balance model would be visualized by the diagram of Fig. G-2-1 and Fig. G-1-1., which clarify the hydrologic cycle in each wadi bsin consisting of two zones: the upper stream (mountain area) and lower stream (coastal area). The terms of the balance equation are shown in Table G-2-1. Fig. G-2-3 summarize the conventional assumptions for the conputation.

Table G-2-1 Terms of the Hydrologic Cycle

Symbols	Terms
Pi	rainfall
Wi	water use
ΔMi	soil moisture
Mi	soil moisture change
Ei*	evapotranspiration of soil moisture
Ei**	evapotranspiration of surface/surface water
Fi	surface runoff
ΔGi	groundwater storage change
Di	surface discharge to lower stream (i=1) or to sea (i=2)
Ii	subsurfce discharge to lower stream (i=1) or to sea (i=2)
Ri*	groundwater recharge fromunsaturated zone
Ri**	groundwater recharge from wadi bed
Bi	wadi bed area

where i = 1; upper streeam, i=2; lower stream

Figure G-2-1 Schematic Diagram of Hydrologic Balance Model



P_1, P_2	:	Rainfall
W_1, W_2	:	Water use
M_1, M_2	:	Soil moisture
ΔM_1, ΔM_2	:	Soil moisture Change
E_1^*, E_2^*	:	Evapotranspiration of soil moisture
E_1^{**}, E_2^{**}	:	Evapotranspiration of surface and subsurface water
E_1, E_2	:	Total evapotranspiration
F_1, F_2	:	Surface runoff
ΔG_1, ΔG_2	:	Groundwater storage change
D_1	:	Surface discharge to lower stream
D_2	:	Surface discharge to sea
R_1^*, R_2^*	:	Groundwater recharge from unsaturated zone
R_1^{**}, R_2^{**}	:	Groundwater recharge from wadi bed
R_1, R_2	:	Groundwater recharge
A_1, A_2	:	Subsurface underflow to alien basin

Fig G-2-2 Schematic Diagram of Hydrologic Balance Terms

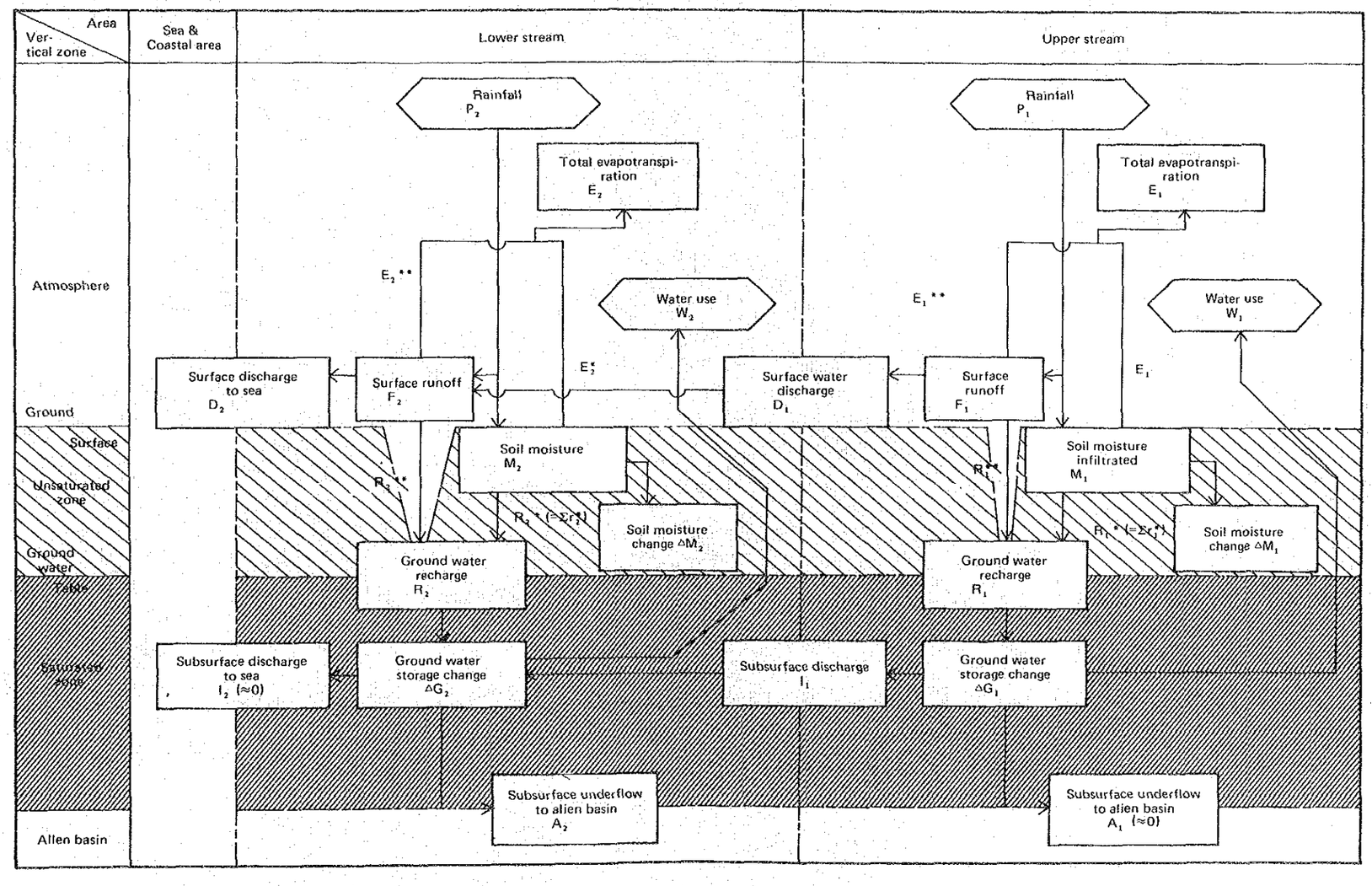
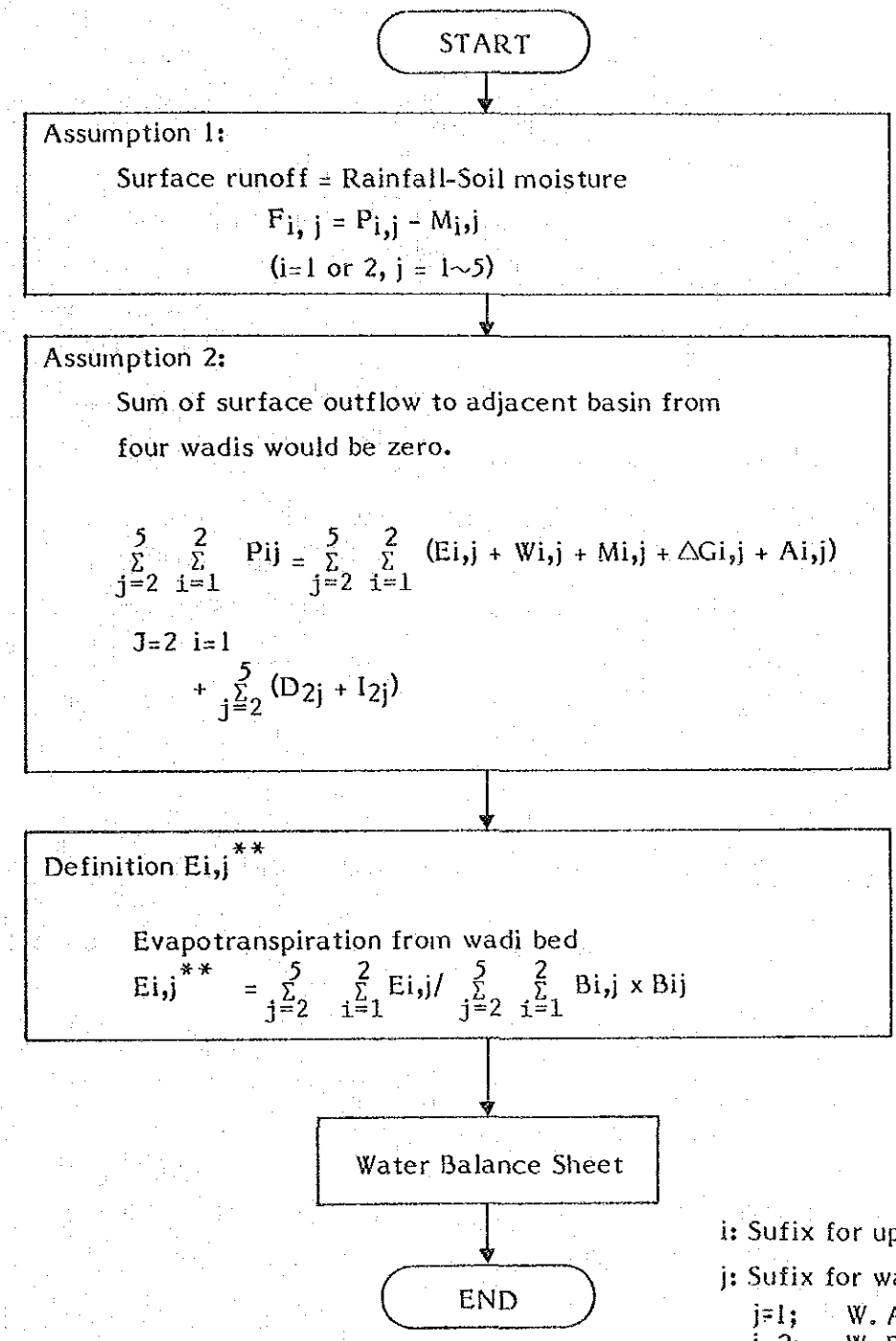


Fig.G-2-3 Conventional Assumptions for Hydrologic Water Balance Estimation



i: Sufix for upper/lower stream

j: Sufix for wadi basin

- j=1; W. Ahin
- j=2; W. B. Ghafir
- j=3; W. Al-Fara'
- j=4; W. B. Kharus
- j=5; W. Al-Ma'awil

2.1 Equations of hydrologic water balance.

The equations of hydrologic water balance are defined as follows:

For each Wadi basin

$$P_i = E_i + W_i + D_i + I_i + M_i + \triangle G_i + A_i \quad \text{..... (G 2.1)}$$

(i = 1; upper stream, i = 2 ; lower stream)

for the whole basin

$$P_1 + P_2 = (E_1 + E_2) + (W_1 + W_2) + D_2 + I_2 + (M_1 + M_2) + (\triangle G_1 + \triangle G_2) + (A_1 + A_2) \quad \text{..... (G-2.2)}$$

and

$$E_i = E_i^* + E_i^{**} \quad \text{..... (G-2.3)}$$

$$F_i = P_i - M_i \quad \text{..... (G-2.4)}$$

$$R = R_1 + R_2 = (R_1 + R_1^{**}) + (R_2^* + R_2^{**}) = (P_1 + P_2) - (M_1 + M_2) = (E_1 + E_2) - D_2 \quad \text{..... (G-2.5)}$$

where i = 1 or 2

2.2. Quantitative Estimations of the Hydrologic Water Balance Terms

In addition to the terms mentioned in 1.1 1.5, other terms for the balance are estimated as follows:

(1) Soil moisture ..... M_i

The soil moisture variation is estimated by the results of soil infiltration capacity experiment and the rainfall data. The value estimated corresponding to the single rainfall is added to the annual amount (Supporting B.5).

(2) Soil moisture change ..... $\triangle M_i$

Annual soil moisture change is supporsed to be zero.

(3) Evapotranspiration of soil moisture ..... E_i*

Penetration of the soil moisture directly to the groundwater is supposed to be very small so that the annual evapotranspiration is assumed to be roughly equal to the annual amount of soil moisture.

(4) Evapotranspiration of surface and subsurface water E_i**

It is assumed that the sum of subsurface outflow to the adjacent basins from each of four wadi basins (Bani Ghafir, Al-Fara', Bani Kharus, Al-Ma'awil) is zero. Total evapotranspiration is calculated as residue of balance equation using Eq. G-2.2. Then by distributing the total residue into four wadis in proportion to the area of modern wadi bed of each wadi, E1* and E2** are calculated. The value obtained per unit area is applied to Wadi Al-Ahin basin.

Table G-2-3 shows the estimated wadi bed area for each basin. Estimated overall evapotranspiration in 4 wadis is presented in Table G-2-4. Estimated evapotranspirations in each wadi bed are summarized in Table G-2-5.

(5) Subsurface runoff to adjacent basin .....A_i

Estimated value of all the balance terms above are inserted into balance equation (Eq. G-2.2) and Ai is obtained as the residue for each.

(6) Total evapotranspiration ..... E_i

$E_i = E_i^* - E_i^{**}$

(7) Surface runoff ..... Fi

$F_i = P_i - M_i$

Table G-2-2 Estimated Results of Annual Evapotranspiration of Soil Moisture

W. Ahin (MCM/Year)

	77	78	79	80	81	82	83	84	Average
Upper	23.0	15.5	19.1	13.4	11.5	29.1	23.2	9.5	18.0
Lower	21.7	11.7	20.1	4.8	11.1	23.9	22.1	3.2	14.8
Basin	44.7	27.2	39.2	18.2	22.6	53.0	45.3	12.7	32.8

W.B.Ghafir (MCM/Year)

	77	78	79	80	81	82	83	84	Average
Upper	31.6	18.5	23.3	26.9	18.1	46.0	24.4	8.6	24.7
Lower	23.1	7.1	17.1	6.1	9.1	33.0	15.2	5.3	14.5
Basin	54.7	25.6	40.4	33.0	27.2	79.0	39.6	13.9	39.2

W. Al-Fara' (MCM/year)

	77	78	79	80	81	82	83	84	Average
Upper	49.6	27.3	36.5	37.8	28.0	74.0	36.9	12.3	37.8
Lower	53.7	17.1	38.6	16.4	28.8	104.1	37.2	7.7	38.0
Basin	103.3	54.5	75.1	54.2	56.6	178.1	74.1	20.0	75.8

W.B. Kharus (MCM/year)

	77	78	79	80	81	82	83	84	Average
Upper	55.3	32.7	32.9	40.3	31.2	69.6	42.6	15.5	40.0
Lower	37.7	16.0	20.1	4.1	26.4	64.1	28.8	3.8	25.1
Basin	93.0	48.7	53.0	44.4	57.6	133.9	71.4	19.3	65.1

W. Al-Ma'awil (MCM/Year)

	77	78	79	80	81	82	83	84	Average
Upper	20.1	12.0	12.8	11.5	13.2	30.1	20.7	1.5	15.2
Lower	31.6	12.3	18.7	4.3	24.2	58.1	34.7	9.8	24.2
Basin	51.7	24.3	31.5	15.8	37.4	88.2	55.4	11.3	39.4

4 Wadis (W. Bani Ghafi ~W. Al-Ma'awil) (MCM/Year)

	77	78	79	80	81	82	83	84	Average
Upper	156.6	90.5	105.5	116.5	90.5	219.7	124.6	37.9	117.7
Lower	146.1	52.5	94.5	30.9	88.5	259.3	115.9	26.6	101.8
Basin	302.7	143.0	200.0	147.4	179.0	479.0	240.5	64.5	219.5

Table G-2-3 Wadi-bed Area Distreibution-Bi

(Km^2)

Wadi Basin District	Wadi Ahin	Wadi Bani Ghafir	Wadi Al-Fara'	Wadi Bani Kharus	Wadi Al-Ma'awil	Total*
Upper Stream	8.4	10.7	19.1	11.5	7.5	57.2 (48.8)
Lower Stream	15.9	19.7	33.5	12.6	30.1	111.8 (95.9)
TOTAL	24.3	30.4	52.6	24.1	37.6	169.0 (144.7)

* Upper; Total of 5 wadis. Lower; Total of 4 wadis (from W.B. Ghafir to W. Al-Ma'awil).

Table G-2-4 Estimated Evapotranspiration from Wadi Bed (for 4 wadis, from Wadi Bani Ghafir to Wadi Al-Ma'awi)-Ei

(MCM/YEAR)

	Rainfall	Soil Moisture	* Water Use	Surface Discharge to sea	Groundwater storage change	Flow to Alien	Evapotranspiration from Wadi Bed **
Volume	585.2	219.5	174.5	14.4	-1.72	0.0	178.5
%	100	37.5	29.7	2.5	-0.3	0.0	30.5

* Table G-1-7.

Table G-2-5 Estimated Evapotranspiration from Wadi Bed

(MCM/Year)

Wadi Basin District	Wadi Ahin	Wadi Bani Ghafir	Wadi Al-Fara'	Wadi Bani Kharus	Wadi Al-Ma'awil	Total*
upper Stream	10.4	13.2	23.6	14.2	9.3	70.7
Lower Stream	19.6	24.3	41.3	15.5	37.1	137.8
TOTAL	30.0	37.5	64.9	29.7	46.4	208.5

2.3 Results of Hydrologic Water Balance Estimation

The estimation was carried out according to the method mentioned above. Among all the balance terms, estimated terms for each year during 1977 - 84 are the followings: rainfall, water use, groundwater storage change in lower stream, evapotranspiration from soil moisture and surface runoff. It is imaginable that the groundwater storage in lower stream is controlled by the long-term hydrologic situation. All the results of the estimated eight-year-average balance terms are tabulated and shown in Table G-2-6.

The upper streams of four wadis, excluding Al-Ma'awail, tend to have positive balance, while lower streams are in negative balance for five wadis. Concerning the whole basin, Wadi Al-Fara' and Wadi Al-Ma'awail are markedly in negative balance, while the others are in positive balance.

The results of estimated hydrologic balance of each wadi are illustrated in Fig. G-2-4.

Table G-2-6 Results of Estimated Hydrologic Water Balance

average between 1976-84
MCM/year

Classification	Balance Terms			Wadi Al-Ahin			Wadi Bani Ghafir			Wadi Al-Fara'			Wadi Bani Kharus			Wadi Al-Ma'awil			Total of 4 Wadis			Wadi Bani Ghafir to Wadi Al-Ma'awil	
	Definition		Simbols	Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	70%	mm/yr
terms to be directly computed in use of observation data obtained through the present project	rainfall		P	90.5	28.3	118.9	98.7	24.3	123.0	127.3	56.5	183.8	138.5	37.3	175.8	51.8	50.8	102.6	416.3	168.9	585.2	100.0	124.6
	water use		W	2.2	7.8	10.0	8.9	29.0	37.9	28.9	27.4	56.3	9.3	20.5	29.8	18.8	31.7	50.5	65.9	108.6	174.5	29.8	37.2
	groundwater storage change		G	-	1.07	(1.07)	-	-0.23	(-0.23)	-	-0.97	(-0.97)	-	-0.41	(-0.41)	-	-0.03	(-0.03)	-	-1.64	(-1.64)		(-1.2)
	subsurface discharge to sea		I_2	-	5.1	5.1	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	0	0
terms to be estimated in effective use of observation data obtained through the present project	soil moisture		M	18.0	14.8	32.8	24.7	14.5	39.2	37.8	38.0	75.8	40.0	25.1	65.1	15.2	24.2	39.4	117.7	101.8	219.5	37.5	46.7
	soil moisture change		M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	evapotranspiration of soil moisture		E*	18.0	14.8	32.8	24.7	14.5	39.2	37.8	38.0	75.8	40.0	25.1	65.1	15.2	24.2	39.4	117.7	101.8	219.5	37.5	46.7
terms to refer to the results reported in the past investigations	surface discharge to sea	*1)	D_2	-	5.5	5.5	-	4.5	4.5	-	4.1	4.1	-	5.4	5.4	-	0.4	0.4	-	14.4	14.4	2.6	3.1
terms to be calculated as the residue of balance equation derived by setting up an assumption	evapotranspiration of surface and subsurface water		E**	10.4	19.6	30.0	13.2	24.3	37.5	23.6	41.3	64.9	14.2	15.5	29.7	9.3	37.1	46.4	60.3	118.2	178.5	30.5	38.0
	subsurface underflow to alien basin		A	-	-	34.43	-	-	4.13	-	-	16.33	-	-	46.21	-	-	-34.07	-	-	≒5)0	0	0
terms to be obtained by simple addition and subtruction of the above terms	total evapotranspiration	*2)	E	28.4	34.4	62.8	37.9	38.8	76.7	61.4	79.3	140.7	54.2	40.6	94.8	24.5	61.3	85.8	170.0	220.0	398.0	68.0	84.7
	surface runoff	*3)	F	72.5	13.5	86.1	74.0	9.8	83.8	89.5	18.5	108.0	98.5	12.2	110.7	36.6	26.6	63.2	298.6	67.1	365.7	62.5	77.9
	groundwater recharge from surface	*4)	R	-	-	50.6	-	-	41.8	-	-	39.0	-	-	75.6	-	-	16.4	-	-	172.8	29.5	36.8

*1) from Horn (1979)
*2) $E = E^* + E^{**}$
*3) $F = P - M$
*4) $R = W+A+I+G$
*5) assumption

$$\sum_{4\ wadi} A = 0$$

*6) $P=E+W+D2+I2+\Delta M+\Delta G+A$
$=E+D2+R+\Delta M$

Fig G-2-4 (1) Flow Diagram Showing the Estimated Results of Hydrologic Balance (Wadi Al-Ahin)

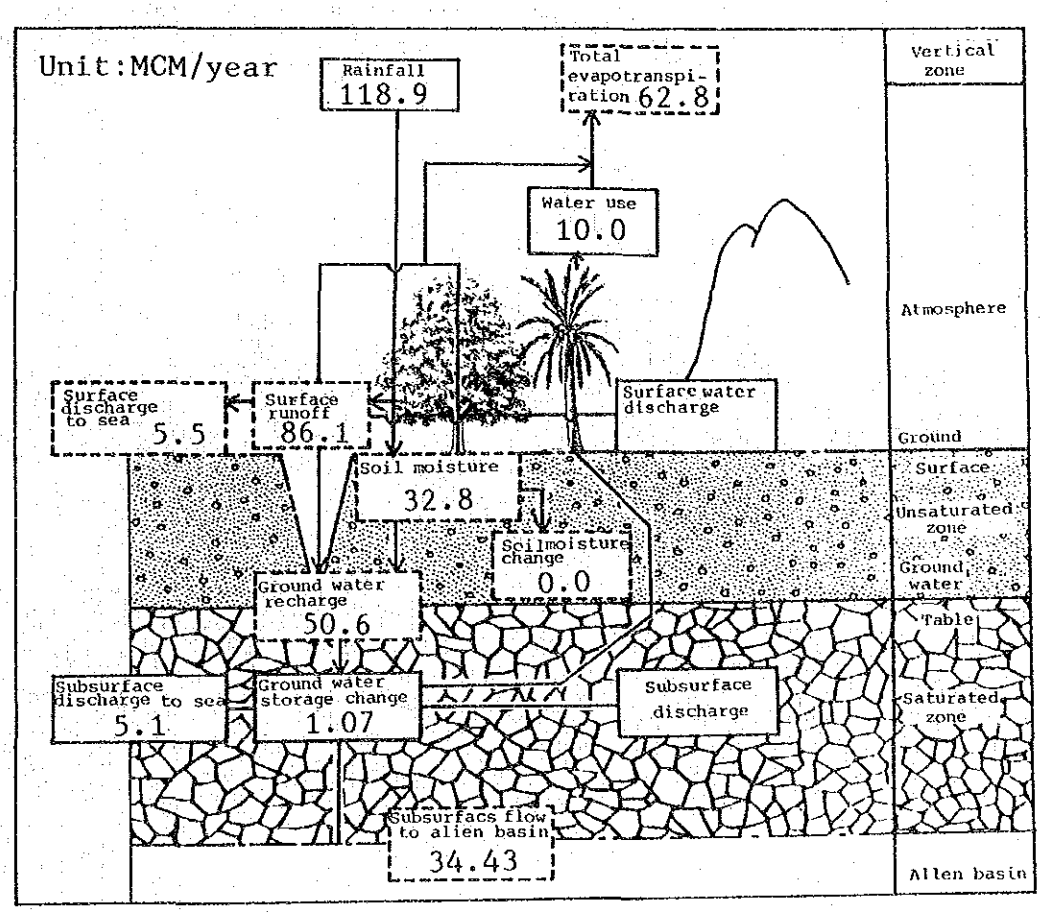


Fig G-2-4 (2) Flow Diagram Showing the Estimated Results of Hydrologic Balance (Wadi Bari Ghafie)

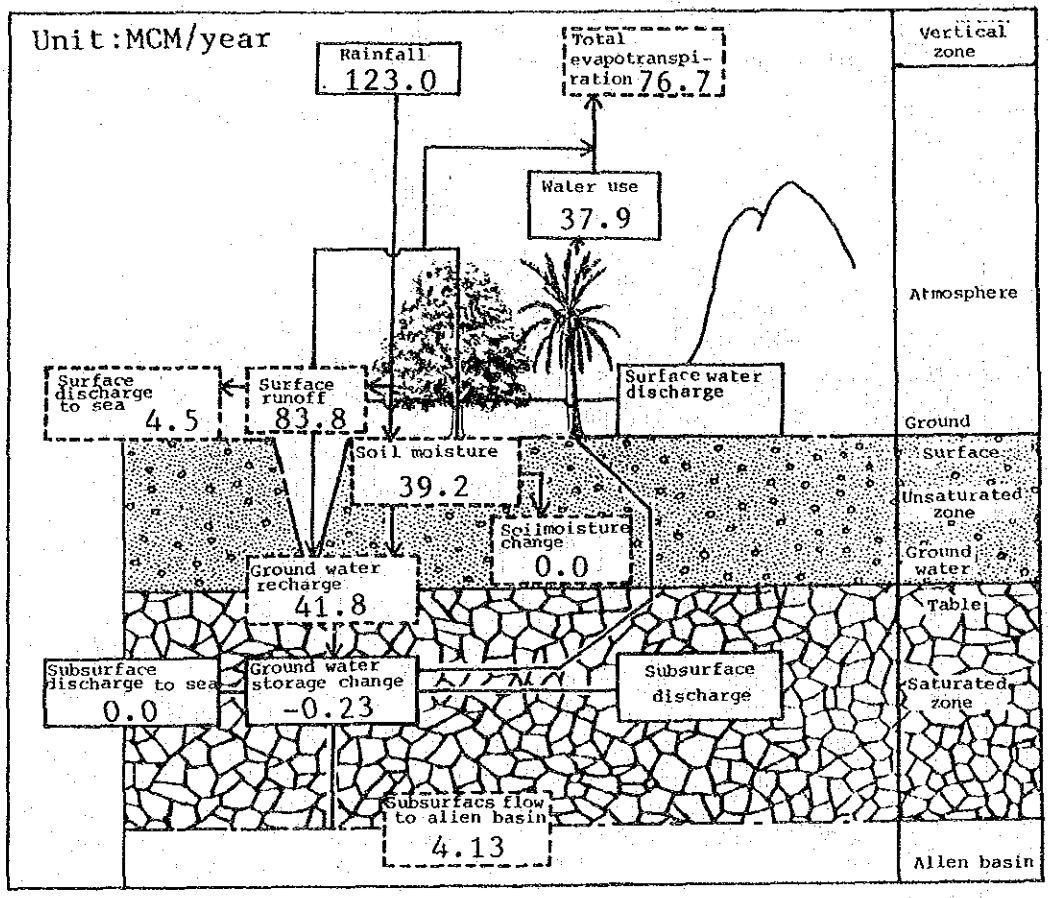


Fig G-2-4 (3) Flow Diagram Showing the Estimated Results of Hydrologic Balance (Wadi Al-Fara')

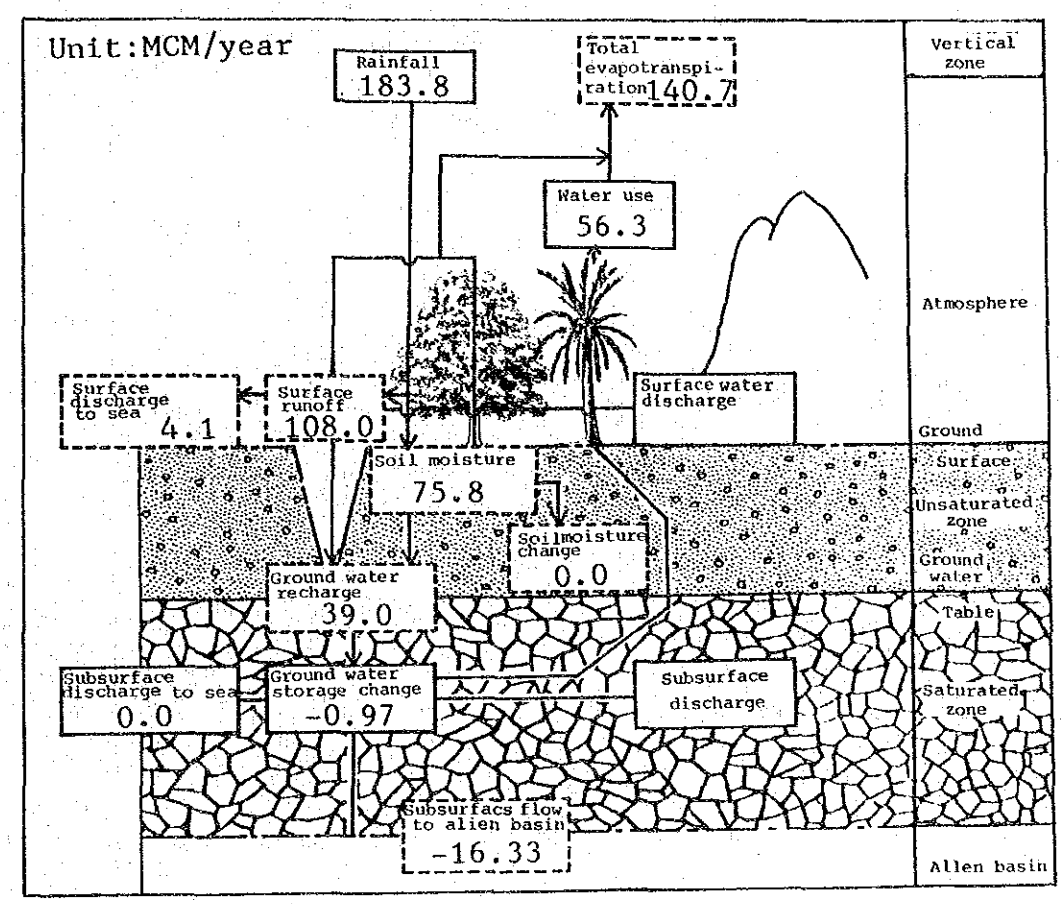


Fig G-2-4 (4) Flow Diagram Showing the Estimated Results of Hydrologic Balance (Wadi Bari Kharus)

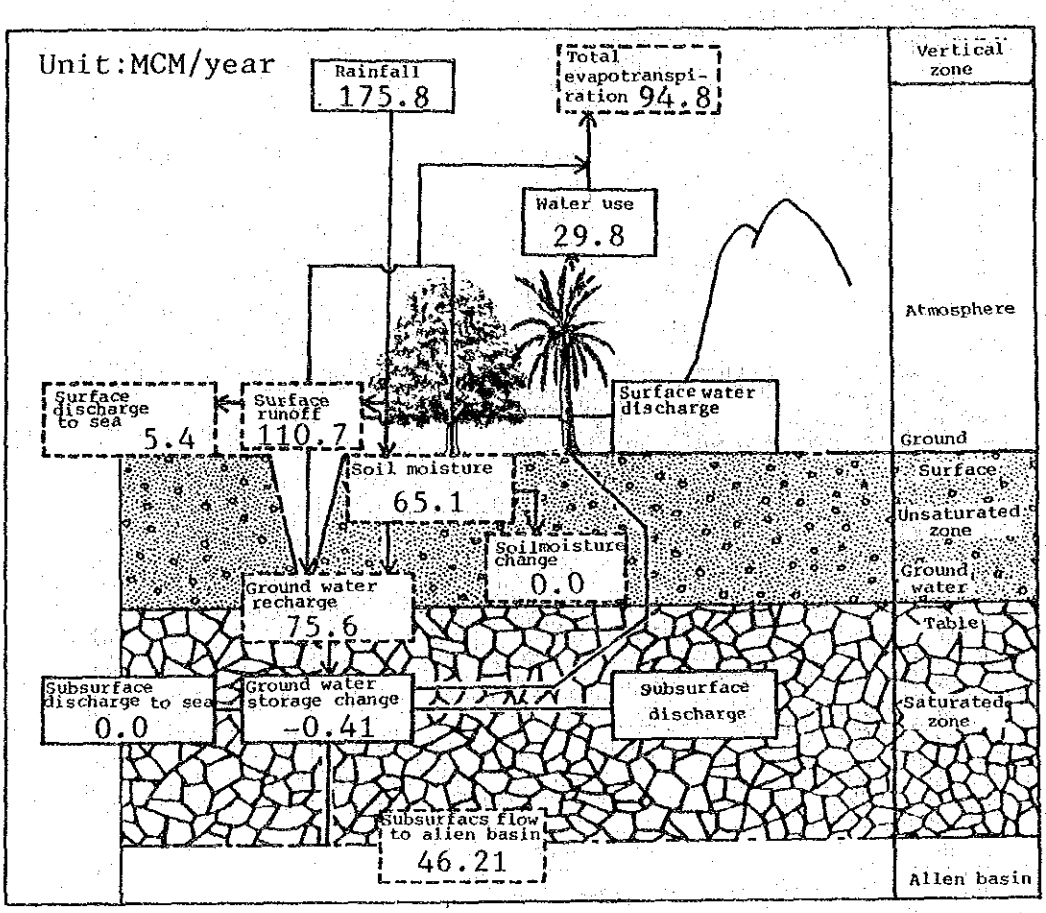
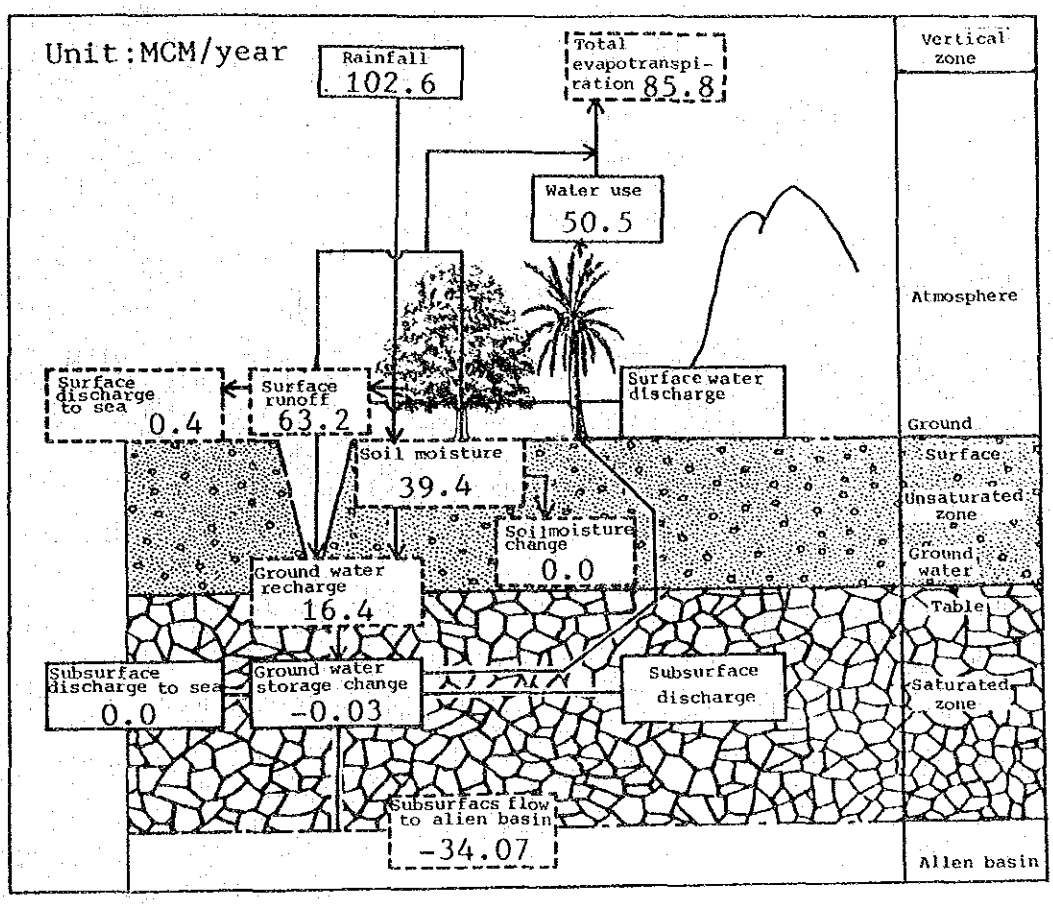


Fig G-2-4 (5) Flow Diagram Showing the Estimated Results of Hydrologic Balance (Wadi Al-Ma'awil)



SUPPORTING REPORT H

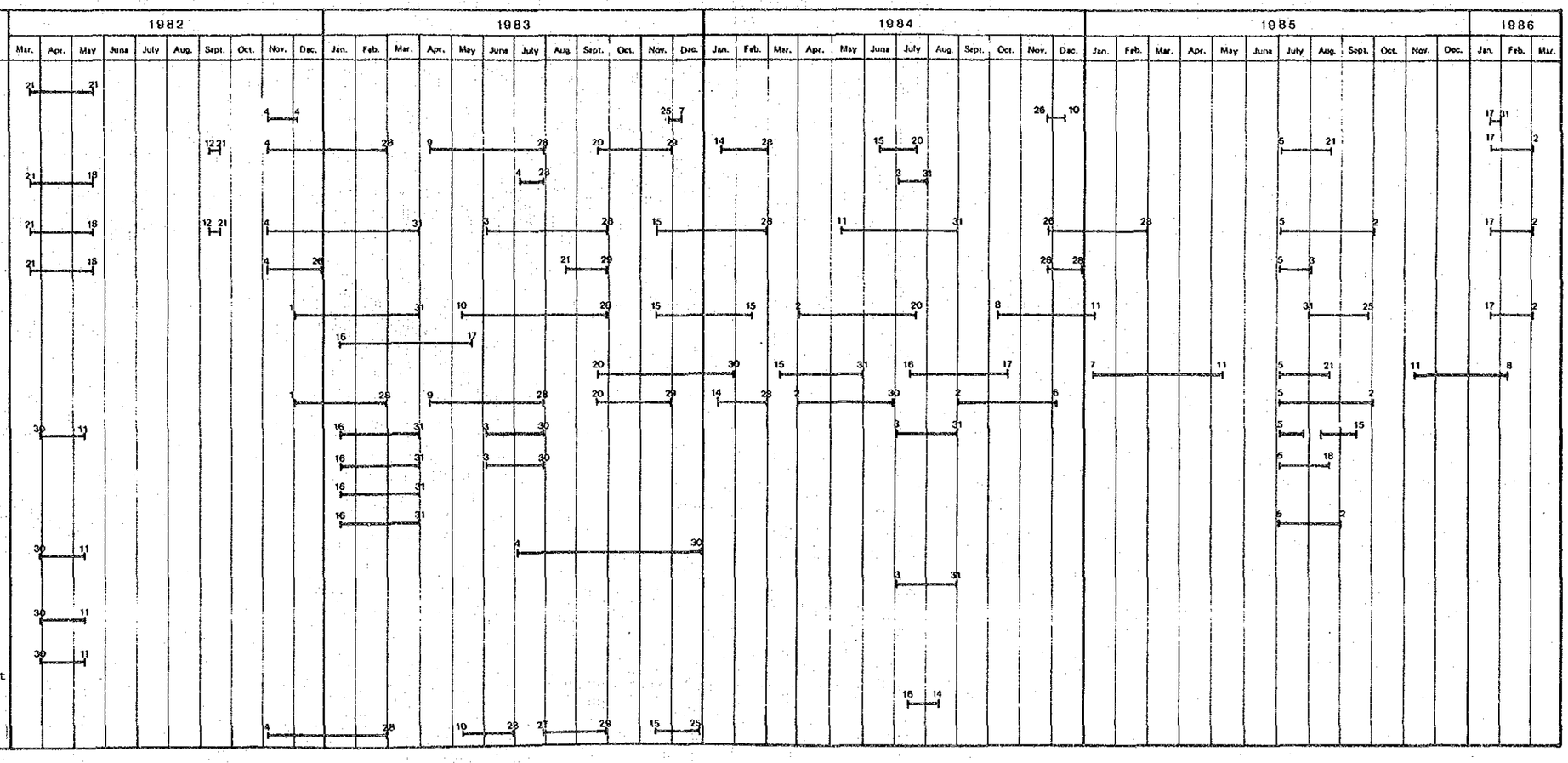
MISCELLANEOUS

SUPPORTING REPORT H

MISCELLANEOUS

1. Field Survey Period of Team Members

NAME	ASSIGNMENT
Dr. ITO Shosuke	Team Leader
Mr. TANAKA Makoto	Team Leader
Mr. TANAKA Hajime	Acting Team Leader
Mr. YOSHIKAWA Mitsuru	Ground-Water Conservation Planning
Mr. USHIKI Hisao	Hydro-geological/ Geo-chemical Survey
Dr. MATSUDA Masuyoshi	Hydro-meteorological Survey
Mr. SAKAMOTO Takao	Hydrological Survey
Mr. SHIONO Yutaka	Hydrological Survey
Mr. SUZUKI Seishiro	Hydrological Survey
Mr. SUIZU Shigeo	Hydro-meteorological
Mr. ISENO Daizo	Water-Use Survey
Mr. DOKIYA Tetsuo	Land-Use Survey
Mr. OHCHI Minoru	Geo-electric Sounding
Mr. KATO Izumi	Geomorphological Survey
Mr. OSHIKA Yusuke	Boring Supervision
Mr. AMATSUJI Yasuhiro	Ground-Water Analysis
Mr. UEDA Tsunehisa	Remote Sensing for Water/Land Use
Mr. GOMI Yoshitaka	Remote Sensing for Environmental Assessment
Dr. NASU Mitsuru	Remote Sensing Analysis
Mr. ISHII Kouichi	Administration



2. Construction and Installation Period of Observation Facilities

Items \ Schedule	1982						1983												1984												1985		
	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
· Agro-meteorological Station																																	
Al-Muladdah				----	----	----	----	----	----	----	----	----	----																				
Al-Rustaq												----	----																				
· Rain-gauge				----	----	----	----	----	----	----	----	----	----																----	----			----
· Wadi Gauge																																	
Concrete tower type				----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----														
Steel pipe type												----	----	----	----	----	----	----	----	----	----												
Radio current meter														----	----				----														
· Observation Well																																	
Well for water level gauging												----	----	----	----	----	----	----															
Well for salinization															----	----	----	----	----														
Existing wells cleaning															----	----	----	----	----	----													
Well level gauges Installation																			----														
· Water use																																	
Cumulative flow mater for pumpage							----	----	----																								
Staff-gauge for discharge of falaj							----	----	----																								

(Remarks)

---- Design and tender

———— Construction (or drilling) and installation

3. Observation Facilities Constructed and Installed during the Survey Period

A. AL-MULADDAH Agro-Meteological Station

B. AL-RUSTAQ Agro-Meteological Station

C. Rain Gauges

D. Wadi Gauges

E. Observation Wells

F. Water Use Survey

(1) List of Observation Facilities

Item No.	Description	Unit	Quantity	Installation Period		
				1983	1984	1985
A.	AL-MULADDAH AGRO-METEOROLOGICAL STATION					
A-1	Observation building	m^2	96.4	○	-	-
A-2	Fences and gates	Site	1	-	○	-
A-3	Meteorological observation equipment	Unit	* 1	○	-	-
B.	AL-RUSTAQ AGRO-METEOROLOGICAL STATION					
B-1	Meteorological observation equipment	Unit	* 1	○	-	-
C.	RAIN GAUGES					
C-1	Fence, gate and concrete base	Site	27	○	○	○
C-2	Rainfall recorder (Excluding two spare units)	Unit	*27	○	○	○
D.	WADI GAUGES					
D-1	Concrete tower type wadi gauge structure	Site	3	○	○	-
D-2	Steel pipe type wadi gauge structure	Site	13	-	○	-
D-3	Water level recorder (Excluding two spare units)	Unit	*16	○	○	-
D-4	Radio flow meter	Unit	* 3	○	○	-

(Contd., 2)

Item No.	Description	Unit	Quantity	Installation Period		
				1983	1984	1985
E.	OBSERVATION WELLS					
E-1	New well	Site	12	-	O	-
E-2	Cleaned well	Site	12	-	O	-
E-3	Water level recorder (Excluding one spare unit)	Unit	*14	-	O	-
F.	WATER USE SURVEY					
F-1	Falaj staff gauge	Site	6	O	-	-
F-2	Cumulative flow meter	Unit	*20	O	-	-

*: Refer to List of Observation Equipment.

4. Observation Equipment for Installation and Maintenance of Observation Facilities

A. Office Equipment

B. Al-MULADDAH Meteorological Equipment

C. Al-RUSTAQ Meteorological Equipment

D. Rain Gauge Equipment

E. Wadi Gauge Equipment

F. Observation Well Equipment

G. Water Use Survey Equipment

H. Field Survey Equipment

List of Observation Equipment

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
A.	OFFICE EQUIPMENT						
A-1	"TOYOTA" Land-Cruser, Station-Wagon Type Model FJ60LV-KC with Standard Accessories. FRAME NO.: ENGINE NO.: 1. FJ60-055534 2F-682115 2. FJ60-053956 2F-676446	Unit	2	2	-	-	-
A-2	Personal Computer PS-80 Interface RS-232C (with Board) Serial No. 9092	Set	1	1	-	-	-
A-3	Printer PT-220	Set	1	1	-	-	-
A-4	Digitizer (Bit Pad One) PBO-11 Interface RS-232C (with Board)	Set	1	1	-	-	-
A-5	Transformer Input: 220 V, 50 Hz Output: 100 V, 50 Hz Cap.: 400 Va	Set	1	1	-	-	-
A-6	Power Stabilizer LC-400	Set	1	1	-	-	-

(Contd..2)

Item No.	Description		Unit	Total Q'ty	Sending-in Period			
					1982	1983	1984	1985
B.	AL-MULADDAH METEOROLOGICAL EQUIPMENT							
B-1	Wind Direction & Speed Transmitter	A-711	Unit	1	1	-	-	-
B-2	Rainfall Transmitter with Anchor Bolts & Nuts	B-011	Unit	1	1	-	-	-
B-3	Solar Radio-Meter	H-201	Unit	2	1	-	1	-
B-4	Soil Thermometer with Cable	E-732	Unit	5	5	-	-	-
B-5	Net Radio-Meter with Accessories	H-221	Unit	2	1	-	1	-
B-6	Dry & Wet Bulb Thermometer	HMT	Unit	4	4	-	-	-
B-7	Heat Flowmeter with Cable	H-908	Unit	5	5	-	-	-
B-8	Wind Direction Conversion Module	M-724	Unit	2	1	-	1	-
B-9	Wind Speed Conversion Module	M-725	Unit	2	1	-	1	-
B-10	Temperature Conversion Module	M-726	Unit	13	9	-	4	-
B-11	Rainfall Conversion Module	M-728	Unit	2	1	-	1	-
B-12	Solar Radio Conversion Module	M-729	Unit	8	6	-	2	-
B-13	V/V Conversion Module	M-758	Unit	7	5	-	2	-

(Contd..3)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
B-14	Two-Pen-Type Recorder with Accessories M-182	Unit	2	1	-	1	-
B-15	Six-Dot-Type Recorder with Accessories M-186	Unit	4	3	-	1	-
B-16	Power Supply Unit with Accessories AC 100 V, 1,200 VA Z-668	Unit	2	1	-	1	-
B-17	Power Stabilizer LC-1000	Unit	1	1	-	-	-
B-18	Transformer Input: 220 V, 50 Hz Output: 100 V, 50 Hz, Cap. 1,000 VA	Pce	1	1	-	-	-
B-19	Battery 12 V, 200 AH with Accessories M-312-15	Pce	1	1	-	-	-
B-20	Large Scale Evaporator with Hook Gauge D-101	Unit	1	1	-	-	-
B-21	ASSMAN'S Psychrometer E-401	Pce	1	1	-	-	-
B-22	(a) Measuring Pole M-023-05 (5.5 m) × 1 pce, M-032 × 1 pce, Arm for Net Radio Meter × 1 pce, M-011-06 × 2 pcs	Set	1	1	-	-	-
	(b) Lightning Rod	Set	1	1	-	-	-

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
	(c) Tool Set for Machinable WPK30 for Electrical S-56	Set	1	1	-	-	-
	(d) Circuit Tester 3209	Set	1	1	-	-	-
	(e) Connecting Cable from Junction Terminal to Panel Board	Set	1	1	-	-	-
	(f) Cable Protection Piping Hard Vinyl Conduit for Cable Protection φ82 × 4 m 28 pcs φ54 × 4 m 8 " φ36 × 4 m 18 " TS Coupling φ82 mm 55 " " φ54 20 " " φ36 35 " Normal Bend φ82 12 " " φ54 8 " " φ36 6 " Entrance Capφ54 14 " " φ36 36 "	Set	1	1	-	-	-
	(g) Junction Terminal Box 03-100 with Supporter	Set	1	1	-	-	-
	(h) Miscellaneous Panel Board M-351-18 Chart Paper for 2-pen-type 36 vol AV-5 Chart Paper for 6-dot-type 108 vol AN-ST12-ER	Set	1	1	-	-	-

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
	Ink for 2-pen-type (red) 30 cc	pcs	30	30	-	-	-
	Ink for 2-pen-type (green) 30 cc	pcs	30	30	-	-	-
	Ink for 6-dot-type 30 cc 24 pcs/set	Set	1	1	-	-	-
	Polyethylene Dome for Net Radio-Meter	pcs	72	72	-	-	-
B-23	Converter Unit Case M-721-08	pcs	3	3	-	-	-
B-24	Cassette Logger DR-55 AC 100 V, 50/60 Hz	Unit	3	2	-	1	-
B-25	Net Radiation Element CN-11 with Shunt Box	Set	1	-	-	1	-
B-26	Net Radiation Fun	Set	1	-	-	1	-
B-27	Heat Flow Sensor H-271	Set	2	-	-	2	-
B-28	Net Radiation Polyethylen Dome	pcs	220	-	-	100	120
B-29	Pen Chip for 2-pen-type Recorder	pcs	2	-	-	2	-
B-30	Gauzes for Wet-bulb Thermometers	pcs	50	-	-	-	50
B-31	Chart for 6 dot-Recorder	Vol	30	-	-	-	30

(Contd..6)

Item No.	Description		Unit	Total Q'ty	Sending-in Period			
					1982	1983	1984	1985
C.	AL-RUSTAQ METEOROLOGICAL EQUIPMENT							
C-1	Earth Thermometer with Cable	E-161-22	Unit	1	1	-	-	-
C-2	Heat Flow Meter	H-908	Unit	2	2	-	-	-
C-3	Large Scale Evaporator with Hook Gauge	D-101	Unit	1	1	-	-	-
C-4	Net Radio-Meter with Accessories	H-221	Unit	1	1	-	-	-
C-5	Six-Dot-Type Recorder with Accessories	M-186	Unit	1	1	-	-	-
C-6	Solar Radio Meter	H-201	Unit	1	1	-	-	-

(Contd..7)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
D.	RAIN GAUGE EQUIPMENT						
D-1	Long Term Rainfall Recorder Model SKI-3 3-months Recording Type with Recording Paper for 1 year Complete with Standard Accessories	Unit	29	18	7	3	-
D-2	Rainfall Recorder Model No. 1250 with Measuring Cylinder	Unit	8	6	2	-	-
D-3	Chart Paper for Recorders	Set	250	-	-	250	-
D-4	Cartridge Pen	pcs	150	-	-	-	150

(Contd..8)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
E.	WADI GAUGE EQUIPMENT						
E-1	Strip-Chart Water Level Recorder R-20 Float 110φ (4.44)	Unit	13	10	2	1	-
	Recording Ink, Chart Paper (4.69) (Code No. 4.3, 4.10, 4.17, 4.36, 4.44, 4.49, 4.52)	Set	12	12	-	-	-
E-2	Strip-Chart Water Level Recorder R-20 Float 250 (4.44) (Code No. 4.3, 4.10, 4.17, 4.36, 4.46, 4.50, 4.52)	Unit	5	3	1	1	-
E-3	Radio Current Meter KS-400	Unit	3	2	1	-	-
E-4	Portable Radio Current Meter KS-400	Unit	3	2	1	-	-
E-5	One-Pen-Type Recorder M-181-Z with Accessories	Unit	1	-	-	1	-
E-6	Recording Device for R-20 Recorder	pcs	100	-	-	60	40
E-7	Chart for R-20 Recorder	pcs	260	-	-	200	60
E 8	Metal Fittings for R-20 Recorder	pcs	10	-	-	10	-
E-9	Float & Weight 250φ	pcs	3	-	-	3	-
E-10	Float & Weight 110φ	pcs	10	-	-	10	-
F-11	Cylindrical Head Screw	pcs	40	-	-	-	40

(Contd..9)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
E-12	Rope Clamp Half	pcs	20	-	-	-	20
E-13	Float Cable, 20m	pcs	10	-	-	-	10
E-14	Float Cable, 10m	pcs	20	-	-	-	20
E-15	Recording Nib	pcs	20	-	-	-	20
E-16	Take-up Spool, Complete	pcs	2	-	-	-	2
E-17	Detector for Radio Current Meter	pcs	1	-	-	-	1
E-18	Convertor for Radio Current Meter	pcs	1	-	-	-	1

(Contd..10)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
F.	OBSERVATION WELL EQUIPMENT						
F-1	Vertical Water Level Recorder Type R-16 Consisting of: Basic Unit (1.1) 250 mm Recording Height Type A Mechanical Clockwork (1.2) for Drum Revolution Periods of 32 days. Pair of Gears (1.9) for A Drum Revolution Periods of 32 days. Float Pulley (1.13) Metric, for Reduction Ratio 1:1-1:100 Tracing Head (1.16) Ink Direct Digital Display (1.17) Metric Float (1.24) 80 mm dia. Counterweight (1.27) 0.25 Kg Float Cable (1.31) 100 m Reducing Caseing (1.19) for 100 mm dia. Tube	Unit	15	-	15	-	-

(Contd..11)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
	Seivel Mount (1.20) with Winding up Pulley (1.22) (Ball Bearing)						
	Sheets of Chart Paper (1.32) 40 sheets						
F-2	Float 80ϕ for R-16 Recorder	pcs	3	-	-	3	-
F-3	Weight 0.25 Kg for R-16 Recorder	pcs	3	-	-	3	-
F-4	Metal Fittings for R-16 Recorder	pcs	3	-	-	3	-
F-5	Recording Device for R-16 Recorder	pcs	130	-	-	30	100
F-6	Ink Cartridge Violet	pcs	30	-	-	-	30
F-7	Ink Bottle Violet	pcs	50	-	-	-	50

(Contd..12)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
G.	WATER USE SURVEY EQUIPMENT						
G-1	Vertical-Axis Helical Type Water Meter Model GTW-75 20 sets Flange ϕ75mm with Bolt 40 pcs Elbow ϕ75mm with Nipple 20 pcs Model GTW-100 10 sets Flange ϕ100mm 20 pcs Elbow ϕ100mm with Nipple 10 pcs Tool Set 1 set	Set	1	1	-	-	-

(Contd..13)

Item No.	Description	Unit	Total Q'ty	Sending-in Period			
				1982	1983	1984	1985
H.	FIELD SURVEY EQUIPMENT						
H-1	Water Bottle 1,000 ml 110 mmϕ	pce	1	1	-	-	-
H-2	Water Bottle 1,000 ml 80 mmϕ	pce	1	1	-	-	-
H-3	Water Quality (Electric Conductivity) Meter with Accessories EST-3	Unit	1	1	-	-	-
H-4	Pocket PH Meter PH-51 Digital-type	pcs	2	2	-	-	-
H-5	Pocket EC Meter SC-51 Digital-type	pcs	3	2	-	-	1
H-6	Portable Level Indicator 2-core type with cable 100m	pcs	6	-	5	-	1
H-7	Geoelectric Instruments Model ES-G2 Potentiometer M/M 2113, S/N 16105 Commutator M/M 2112, S/N 16106	Set	1	1	-	-	-
H-8	Logging Instruments Model Geollo 300	Set	1	1	-	-	-
H-9	Graduation Plate of Water Level	pcs	110	90	-	-	20
H-10	Cemedine 3 Kg/can No. 195	Can	10	-	-	5	5
H-11	Electro Distance Meter Theodolite TOPCON GTS-2B	Set	1	-	-	-	1